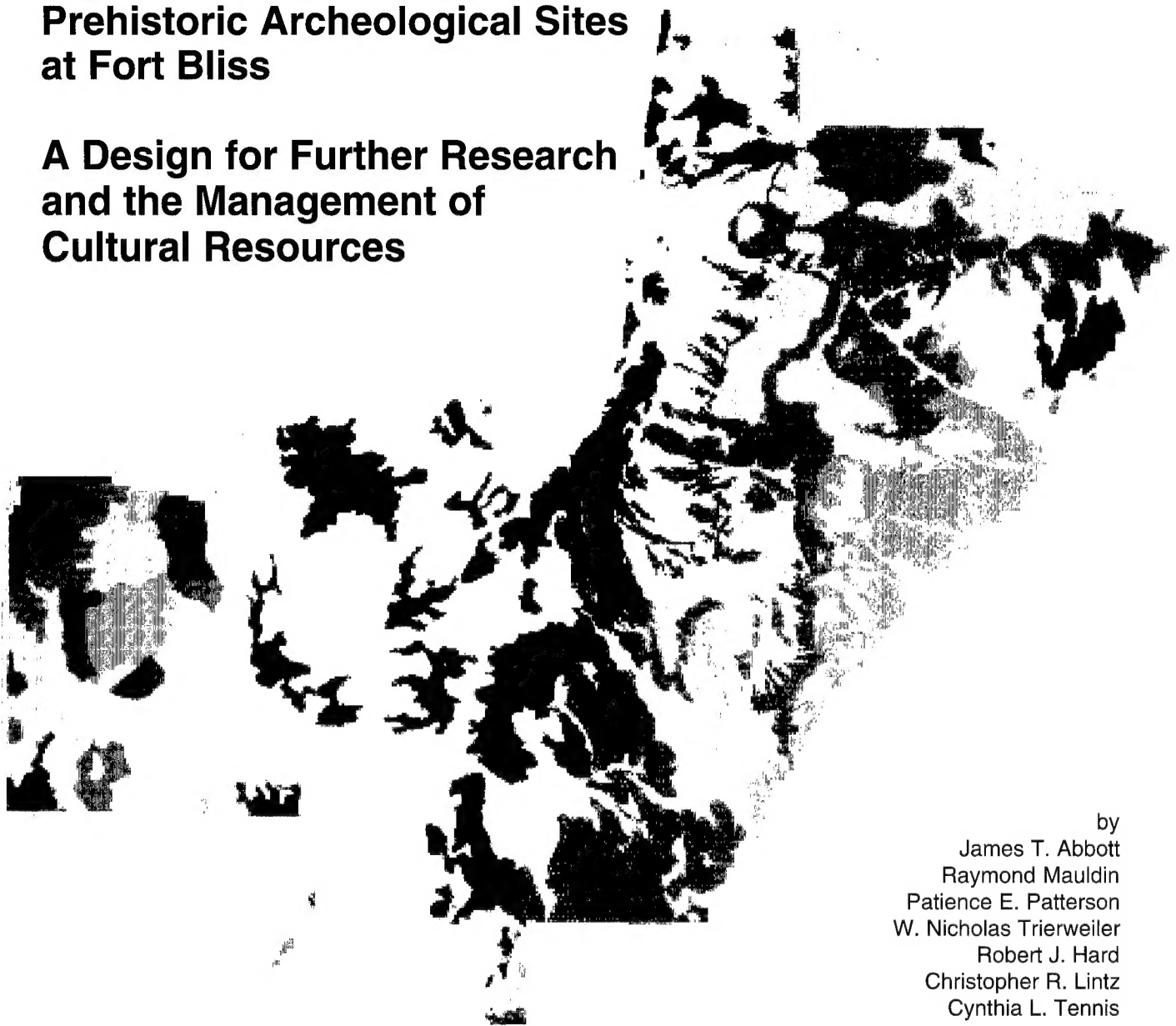


Significance Standards for Prehistoric Archeological Sites at Fort Bliss

A Design for Further Research and the Management of Cultural Resources



by
James T. Abbott
Raymond Mauldin
Patience E. Patterson
W. Nicholas Trierweiler
Robert J. Hard
Christopher R. Lintz
Cynthia L. Tennis

DISTRIBUTION STATEMENT A

Approved for public release;
Distribution Unlimited

US ARMY CORPS OF ENGINEERS
Fort Worth District



TRC *Mariah
Associates Inc.*

DISTRIBUTION STATEMENT A:

APPROVED FOR PUBLIC RELEASE: DISTRIBUTION IS UNLIMITED

DISTRIBUTION STATEMENT B:

DISTRIBUTION AUTHORIZED TO U.S. GOVERNMENT AGENCIES ONLY;
(Indicate Reason and Date Below). OTHER REQUESTS FOR THIS DOCUMENT SHALL BE REFERRED
TO (Indicate Controlling DoD Office Below).

DISTRIBUTION STATEMENT C:

DISTRIBUTION AUTHORIZED TO U.S. GOVERNMENT AGENCIES AND THEIR CONTRACTORS;
(Indicate Reason and Date Below). OTHER REQUESTS FOR THIS DOCUMENT SHALL BE REFERRED
TO (Indicate Controlling DoD Office Below).

DISTRIBUTION STATEMENT D:

DISTRIBUTION AUTHORIZED TO DOD AND U.S. DOD CONTRACTORS ONLY; (Indicate Reason
and Date Below). OTHER REQUESTS SHALL BE REFERRED TO (Indicate Controlling DoD Office Below).

DISTRIBUTION STATEMENT E:

DISTRIBUTION AUTHORIZED TO DOD COMPONENTS ONLY; (Indicate Reason and Date Below).
OTHER REQUESTS SHALL BE REFERRED TO (Indicate Controlling DoD Office Below).

DISTRIBUTION STATEMENT F:

FURTHER DISSEMINATION ONLY AS DIRECTED BY (Indicate Controlling DoD Office and Date
Below) or HIGHER DOD AUTHORITY.

DISTRIBUTION STATEMENT X:

DISTRIBUTION AUTHORIZED TO U.S. GOVERNMENT AGENCIES AND PRIVATE INDIVIDUALS
OR ENTERPRISES ELIGIBLE TO OBTAIN EXPORT-CONTROLLED TECHNICAL DATA IN ACCORDANCE
WITH DOD DIRECTIVE 5230.25, WITHHOLDING OF UNCLASSIFIED TECHNICAL DATA FROM PUBLIC
DISCLOSURE, 6 Nov 1984 (Indicate date of determination). CONTROLLING DOD OFFICE IS (Indicate
Controlling DoD Office).

The cited documents has been reviewed by competent authority and the following distribution statement is
hereby authorized.

A

(Statement)

NON-SENSITIVE
HISTORICAL INFORMATION
(Reason)

Jay R. Newman
(Signature & Typed Name)

CFSWF-PL-RC
(Assigning Office)

USACOE Ft. WORTH
DISTRICT TX.
(Controlling DoD Office Name)

P.O.B. 17300 Ft. WORTH
TX. 76102-0300
(Controlling DoD Office Address,
City, State, Zip)

10-3-96
(Date Statement Assigned)

Significance Standards for Prehistoric Archeological Sites at Fort Bliss:

*A Design for Further Research and the
Management of Cultural Resources*

by

James T. Abbott
Raymond Mauldin
Patience E. Patterson
W. Nicholas Trierweiler
Robert J. Hard
Christopher R. Lintz
Cynthia L. Tennis

DTIC QUALITY INSPECTED 2

prepared for

U.S. Army Engineer District, Fort Worth

under contract

DACA63-92-D-0011 - Delivery Order No. 18

19961015 036

prepared by

TRC MARIAH ASSOCIATES INC.
Austin, Texas

unclassified

SECURITY CLASSIFICATION OF THIS PAGE

| REPORT DOCUMENTATION PAGE | | | | Form Approved OMB No. 0704-0188 | |
|---|--|--|--|---|--|
| 1a. REPORT SECURITY CLASSIFICATION Unclassified | | 1b. RESTRICTIVE MARKINGS none | | | |
| 2a. SECURITY CLASSIFICATION AUTHORITY n/a | | 3. DISTRIBUTION/AVAILABILITY OF REPORT Public Access Unlimited Distribution | | | |
| 2b. DECLASSIFICATION/DOWNGRADING SCHEDULE n/a | | | | | |
| 4. PERFORMING ORGANIZATION REPORT NUMBER(S) Technical Report No. 01735-18 | | 5. MONITORING ORGANIZATION REPORT NUMBER(S) | | | |
| 6a. NAME OF PERFORMING ORGANIZATION TRC Mariah Associates Inc. | | 6b. OFFICE SYMBOL Austin, Texas | | 7a. NAME OF MONITORING ORGANIZATION US Army Corps of Engineers, Ft. Worth District | |
| 6c. ADDRESS (City, State, and ZIP Code) 3939 Bee Caves Road, Bldg. C Austin, Texas 78746 | | 7b. ADDRESS (City, State, and ZIP Code) P.O. Box 17300 Fort Worth, Texas, 76102 | | | |
| 8a. NAME OF FUNDING/SPONSORING ORGANIZATION Department of the Army - Fort Bliss Directorate of Environment | | 8b. OFFICE SYMBOL | | 9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER DACA63-92-D-0011; Delivery Order No. 18 | |
| 8c. ADDRESS (City, State, and ZIP Code) ATZC-DOE Fort Bliss, Texas, 79916-6816 | | 10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. NO. PROJECT NO. TASKWORK UNIT ACCESSION NO. | | | |
| 11. TITLE (Include Security Classification) Significance Standards for Prehistoric Archeological Sites at Fort Bliss: A Design for Further Research and the Management of Cultural Resources | | | | | |
| 12. PERSONAL AUTHOR(S) James Abbott, Raymond Mauldin, Patience Patterson, Robert Hard, W. Nicholas Trierweiler, Christopher Lintz, and Cynthia Tennis | | | | | |
| 13a. TYPE OF REPORT Final | | 13b. TIME COVERED From 95 Jan to 96 Aug | | 14. DATE OF REPORT (Year, Month, Day) 1996 August 15 | |
| 15. PAGE COUNT 338 | | | | | |
| 16. SUPPLEMENTARY NOTATION none | | | | | |
| 17. COSATI CODES FIELD GROUP SUB-GROUP | | 18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number) archeology, geoarcheology, cultural resources, prehistory, antiquities, Fort Bliss, Texas, New Mexico, National Register of Historic Places | | | |
| 19. ABSTRACT (Continue on reverse if necessary and identify by block number) This document is a design for future archeological research at Fort Bliss. It reviews previous archeological work in the region, assesses the current body of relevant knowledge, and suggests specific avenues for further inquiry. The scientific research design is intended to be a component in the Cultural Resources Management Plan (CRMP) for Fort Bliss. In conjunction, the research design and the CRMP will facilitate determinations of eligibility for the National Register of Historic Places (NRHP) for those prehistoric archeological resources managed by the Fort. Research contexts for historic archeological and historic architectural resources are not included in this research design. <div style="text-align: right;">(continued)</div> | | | | | |
| 20. DISTRIBUTION/AVAILABILITY OF ABSTRACT [X] UNCLASSIFIED/UNLIMITED [] SAME AS RPT. [] DTIC USERS | | 21. ABSTRACT SECURITY CLASSIFICATION n/a | | | |
| 22a. NAME OF RESPONSIBLE INDIVIDUAL Mr. Jay Newman | | 22b. TELEPHONE (Include Area Code) (817) 885-6388 | | 22c. OFFICE SYMBOL CESWF-PL-RC | |

19. ABSTRACT (Continued)

The theoretical perspective of the research design is explicitly materialistic with a rational-functional approach to explaining human behavior. The research framework also adopts a systems theory approach in which human societies are considered to be intricate systems of variables with ever-changing relationships. Applying a cultural ecological framework, the research design attempts to identify the adaptive strategies by which societies survive within the constraints set by their environments. Within this approach, the research presumes economic optimization, such that human societies tend to identify and select those sets of behaviors with the maximum net utility.

The research design first develops a series of natural and cultural contexts for future research by examining the natural environment of the Fort Bliss region, the range of cultural adaptations to such environments, and the extant body of relevant archeological information. This examination includes a critical review of currently accepted constructs of local prehistory. Based on these contexts, seven domains of research are delineated: chronometrics, geoarcheology, paleoenvironment, technology, settlement patterns, subsistence, and cultural interaction. Within each domain, a series of research questions are posed, and the data needed to address those questions are identified.

Following delineation of the seven domains, the design concludes by discussing application of the research questions. It reviews characteristics of the existing Fort Bliss site database, with special attention to geomorphic and methodological biases which may affect data reliability. Sampling is discussed as a strategy for managing the tens of thousands of sites on the Fort. Finally, based on the data needed to address the seven domains, a preliminary model is developed for evaluating the research value and significance of prehistoric archeological sites at Fort Bliss.

EXECUTIVE SUMMARY

This document is a design for future archeological research at Fort Bliss. It reviews previous archeological work in the region, assesses the current body of relevant knowledge, and suggests specific avenues for further inquiry. The scientific research design is intended to be a component in the Cultural Resources Management Plan (CRMP) for Fort Bliss. In conjunction, the research design and the CRMP will facilitate determinations of eligibility for the National Register of Historic Places (NRHP) for those prehistoric archeological resources managed by the Fort. Research contexts for historic archeological and historic architectural resources are not included in this research design.

The theoretical perspective of the research design is explicitly materialistic with a rational-functional approach to explaining human behavior. The research framework also adopts a systems theory approach in which human societies are considered to be intricate systems of variables with ever-changing relationships. Applying a cultural ecological framework, the research design attempts to identify the adaptive strategies by which societies survive within the constraints set by their environments. Within this approach, the research presumes economic optimization, such that human societies tend to identify and select those sets of behaviors with the maximum net utility.

The research design first develops a series of natural and cultural contexts for future research by examining the natural environment of the Fort Bliss region, the range of cultural adaptations to such environments, and the extant body of relevant archeological information. This examination includes a critical review of currently accepted constructs of local prehistory. Based on these contexts, seven domains of research are delineated: chronometrics, geoarcheology, paleoenvironment, technology, settlement patterns, subsistence, and cultural interaction. Within each domain, a series of research questions are posed, and the data needed to address those questions are identified.

Following delineation of the seven domains, the design concludes by discussing application of the research questions. It reviews characteristics of the existing Fort Bliss site database, with special attention to geomorphic and methodological biases which may affect data reliability. Sampling is discussed as a strategy for managing the tens of thousands of sites on the Fort. Finally, based on the data needed to address the seven domains, a preliminary model is developed for evaluating the research value and significance of prehistoric archeological sites at Fort Bliss.

ACKNOWLEDGEMENTS

Development of this research design was authorized by the U.S. Army Engineer District, Fort Worth, with funding provided by Fort Bliss. Technical Representatives for the Army were first Tim Dalbey and later Jay Newman.

Many Fort Bliss personnel were helpful in the development of this research design, ferreting out elusive literature and engaging in stimulating discussions. We acknowledge their gracious assistance. Joe Brandon provided us with a brief guided tour of McGregor Range and also supplied hardcopy output from the Fort Bliss GRASS System. Galen Burgett provided access to a number of fugitive gray literature documents. Tim Church offered his insights into lithic sources on the Fort and provided copies of critical documents. Fred Almaraz also offered his insights into the cave and rockshelter survey in the Hueco Mountains and provided copies of relevant articles and papers. Carlos Caraveo was helpful with his information on the on-going lithic source study. Jeff Leach and Tom O'Laughlin both provided key information and Carol Hedrick supplied several documents. Jim Bowman and Galen Burgett reviewed a first draft of the research design and their comments and suggestions for improvements were much appreciated.

Other persons who were helpful include Rick Hubbard who provided access to a number of gray literature reports, and Ronna Jane Bradley who was very helpful with copies of pertinent articles and her insights and knowledge of Casas Grandes and the Jornada region. Finally, Steven Tomka, Jay Peck, and Marybeth Tomka all participated in lively discussions.

Primary authors of the research design are James Abbott, Patience Patterson, Ray Mauldin, and Robert Hard. Chris Lintz authored much of Chapter 7.0, and Cynthia Tennis contributed to Chapter 10.0. Nick Trierweiler contributed Chapters 1.0 and 11.0, coordinated and edited the document, and managed the project for TRC Mariah. Jim States was Executive Manager and Quality Assurance Officer, and Chris Turnbow conducted a peer review of the first draft. Steve Berg and Bill Hudspeth drafted the AutoCAD illustrations. Renaissance Editing conducted a technical edit of the first draft and document production was supervised by debora White.

The authors thank all of the above people. We acknowledge the wide spectrum of archeological opinions at Fort Bliss and in the Jornada, as well as the difficulties in accessing the grey literature of unpublished and ongoing research. We do not expect that the research design will satisfy all portions of the archeological community. Indeed, while developing the research design we were occasionally reminded of Abraham Lincoln's statement about politicians being unable to "fool all of the people all of the time," and we are tempted to paraphrase this as "pleasing all of the archeologists all of the time..." Nonetheless, we hope that the research design provides a useful framework for structuring future inquiries at Fort Bliss, and a departure point for future designs.

TABLE OF CONTENTS**Page****PART I: RESEARCH CONTEXT**

| | | |
|---------|--|----|
| 1.0 | INTRODUCTION/OVERVIEW | 1 |
| 1.1 | OVERVIEW OF FORT BLISS | 1 |
| 1.1.1 | History | 1 |
| 1.1.2 | Archeology and Cultural Resource Management | 3 |
| 1.2 | PURPOSE AND SCOPE OF THE RESEARCH DESIGN | 4 |
| 1.2.1 | Requirements | 4 |
| 1.2.2 | Development of Significance Standards | 5 |
| 1.2.2.1 | The Nature of Research Designs | 5 |
| 1.2.2.2 | Using Research Designs | 5 |
| 1.2.3 | Limitations of this Research Design | 6 |
| 1.2.4 | Theoretical Orientation | 7 |
| 1.2.5 | Structure of the Research Design | 7 |
| 2.0 | NATURAL ENVIRONMENT | 9 |
| 2.1 | PHYSIOGRAPHY | 9 |
| 2.2 | MODERN CLIMATE | 14 |
| 2.3 | SOILS | 14 |
| 2.4 | FLORA AND FAUNA | 19 |
| 2.4.1 | Modern Vegetation | 19 |
| 2.4.2 | Modern Fauna | 25 |
| 2.5 | BEDROCK GEOLOGY | 29 |
| 2.5.1 | Stratigraphy | 29 |
| 2.5.2 | Structure, Paleotectonics, and Neotectonics | 32 |
| 2.6 | HISTORICAL GEOLOGY AND LATE CENOZOIC STRATIGRAPHY | 34 |
| 2.7 | HYDROLOGY | 40 |
| 2.8 | PALEOCLIMATE AND PALEOENVIRONMENT | 41 |
| 3.0 | PREVIOUS RESEARCH IN THE REGION | 45 |
| 3.1 | CURRENT CULTURAL HISTORY MODELS | 45 |
| 3.2 | INITIAL ARCHEOLOGICAL RECONNAISSANCE IN THE REGION | 49 |
| 3.3 | INITIAL SYNTHESIS AND SUPPORTING WORK | 50 |
| 3.4 | DATA ACQUISITION AND SYSTEMATICS | 52 |
| 3.4.1 | Synchronic Models | 53 |
| 3.4.2 | Fluctuating/Competing Adaptations | 54 |
| 3.4.3 | Nonsite and Landscape Issues | 55 |
| 3.5 | SUMMARY | 56 |

TABLE OF CONTENTS (CONTINUED)
Page**PART II: RESEARCH DOMAINS**

| | | |
|---------|--|----|
| 4.0 | CHRONOMETRICS RESEARCH DOMAIN | 57 |
| 4.1 | CHRONOMETRIC DATING TECHNIQUES | 58 |
| 4.1.1 | Luminescence Dating | 58 |
| 4.1.2 | Electron-spin Resonance Dating | 60 |
| 4.1.3 | Uranium Series Disequilibrium Dating | 61 |
| 4.1.4 | Radiocarbon Dating | 61 |
| 4.1.4.1 | Radiocarbon Dating of Wood, Charcoal, and Other Plant Remains | 63 |
| 4.1.4.2 | Radiocarbon Dating of Bone and Shell | 63 |
| 4.1.4.3 | Radiocarbon Dating of Soils and Sediments | 64 |
| 4.1.4.4 | Radiocarbon Dating of Soil Carbonates | 69 |
| 4.1.4.5 | Other Applications of Radiocarbon Dating | 69 |
| 4.1.5 | Oxidizable Carbon Ratio Dating | 70 |
| 4.1.6 | Fission-track Dating | 71 |
| 4.1.7 | Cosmogenic Isotope Dating | 72 |
| 4.1.8 | Archeomagnetic Dating | 72 |
| 4.1.9 | Dendrochronology | 72 |
| 4.2 | QUASI-CHRONOMETRIC DATING TECHNIQUES | 73 |
| 4.2.1 | Obsidian Hydration | 73 |
| 4.2.2 | Chert Patination | 74 |
| 4.2.3 | Amino Acid Racemization | 74 |
| 4.2.4 | Cation-Ratio Dating | 75 |
| 4.3 | RELATIVE AND CORRELATIVE DATING TECHNIQUES | 75 |
| 4.3.1 | Soil Development | 75 |
| 4.3.2 | Geomorphic Position | 76 |
| 4.3.3 | Stratigraphy and Superposition | 76 |
| 4.3.4 | Artifact Seriation and Crossdating | 77 |
| 4.4 | RESEARCH QUESTIONS | 79 |
| 5.0 | GEOARCHEOLOGICAL RESEARCH DOMAIN | 83 |
| 5.1 | EOLIAN PROCESSES AND LANDFORMS | 83 |
| 5.1.1 | Eolian Processes | 83 |
| 5.1.2 | Eolian Landforms | 84 |
| 5.1.2.1 | Erosional Eolian Landforms | 85 |
| 5.1.2.2 | Depositional Eolian Landforms | 85 |
| 5.1.3 | Paleoclimatic Implications of Eolian Deposits | 90 |
| 5.1.4 | Geoarcheological Implications of Eolian Processes and Deposits | 91 |
| 5.1.4.1 | Eolian Setting Implication #1 | 91 |
| 5.1.4.2 | Eolian Setting Implication #2 | 91 |
| 5.1.4.3 | Eolian Setting Implication #3 | 92 |
| 5.1.4.4 | Eolian Setting Implication #4 | 92 |
| 5.1.4.5 | Eolian Setting Implication #5 | 92 |

TABLE OF CONTENTS (CONTINUED)

| | <u>Page</u> |
|---|-------------|
| 5.1.4.6 Eolian Setting Implication #6 | 95 |
| 5.1.4.7 Eolian Setting Implication #7 | 95 |
| 5.1.5 Eolian Record in the Fort Bliss Region | 95 |
| 5.1.6 Research Questions | 101 |
| 5.1.6.1 Site-Specific Research Questions | 101 |
| 5.1.6.2 Regional Eolian Research Questions | 102 |
| 5.2 ALLUVIAL FAN PROCESSES AND LANDFORMS | 103 |
| 5.2.1 Alluvial Fan Processes | 104 |
| 5.2.2 Alluvial Fan Deposits | 106 |
| 5.2.3 Climatic Implications of Alluvial Fan Activity and Quiescence | 108 |
| 5.2.4 Geoarcheological Implications of the Alluvial Fan Environment | 110 |
| 5.2.5 Alluvial Fans on Fort Bliss | 111 |
| 5.2.6 Research Questions | 112 |
| 5.2.6.1 Site-Specific Questions | 112 |
| 5.2.6.2 Regional Questions | 113 |
| 5.3 UPLAND AND SLOPE ENVIRONMENTS | 114 |
| 5.3.1 Slope Processes | 114 |
| 5.3.2 Slope Landforms | 116 |
| 5.3.3 Climatic Implications of Slope Activity | 117 |
| 5.3.4 Geoarcheological Implications of Slope Environments | 119 |
| 5.3.5 Slope Environments on Fort Bliss | 119 |
| 5.3.6 Research Questions | 120 |
| 5.4 LACUSTRINE PROCESSES AND PLAYAS | 121 |
| 5.4.1 Mechanisms of Playa Formation | 121 |
| 5.4.2 Climatic Implications of Playas | 122 |
| 5.4.3 Geoarcheological Implications of Playas | 123 |
| 5.4.4 Playas on Fort Bliss | 123 |
| 5.4.5 Research Questions | 124 |
| 5.5 SOIL PROCESSES, SOIL MORPHOLOGY, AND SOIL GEOMORPHOLOGY . . | 125 |
| 5.5.1 Soil-Forming Processes | 126 |
| 5.5.1.1 Organic Matter | 126 |
| 5.5.1.2 Weathering | 126 |
| 5.5.1.3 Carbonate Translocation and Accumulation | 127 |
| 5.5.1.4 Clay Translocation and Accumulation | 130 |
| 5.5.1.5 Turbation | 130 |
| 5.5.2 Soil Geomorphology | 131 |
| 5.5.3 Geoarcheological Implications of Soils and Paleosols | 131 |
| 5.5.4 Soil Geomorphology of Fort Bliss | 132 |
| 5.5.5 Research Questions | 134 |
| 5.6 GEOARCHEOLOGY AND CONTEXTUAL INTEGRITY | 135 |

TABLE OF CONTENTS (CONTINUED)

| | <u>Page</u> |
|--|-------------|
| 6.0 PALEOENVIRONMENTAL RESEARCH DOMAIN | 139 |
| 6.1 NATURE OF THE EVIDENCE | 139 |
| 6.1.1 Historical Evidence | 139 |
| 6.1.2 Global Circulation Models | 139 |
| 6.1.3 Proxy Evidence | 140 |
| 6.1.4 Direct Evidence | 142 |
| 6.2 DIRECT AND PROXY SOURCES OF PALEOENVIRONMENTAL INFORMATION | 143 |
| 6.2.1 Macrobotanical Information | 143 |
| 6.2.2 Pollen and Phytoliths | 144 |
| 6.2.3 Tree Rings | 145 |
| 6.2.4 Diatoms | 146 |
| 6.2.5 Fauna | 146 |
| 6.2.6 Stable Isotopes | 147 |
| 6.2.7 Human Skeletal Remains and Coprolites | 149 |
| 6.2.8 Soil Morphology | 149 |
| 6.2.9 Stratigraphy and Sedimentology | 149 |
| 6.2.10 Tufa and Speleothems | 149 |
| 6.2.11 Historical Records | 150 |
| 6.3 SUMMARY AND CRITIQUE OF EXTANT PALEOENVIRONMENTAL EVIDENCE IN THE FORT BLISS REGION | 150 |
| 6.3.1 Summary of Late Quaternary Paleoenvironmental Information | 150 |
| 6.3.2 Cautionary Critique of Extant Data | 153 |
| 6.4 PALEOENVIRONMENTAL RESEARCH QUESTIONS | 157 |
| 7.0 TECHNOLOGY RESEARCH DOMAIN | 161 |
| 7.1 BACKGROUND DISCUSSIONS | 161 |
| 7.2 THEORETICAL MODELS AND EXPLANATORY APPROACHES | 163 |
| 7.2.1 The Material Types and Spatial Dimension | 164 |
| 7.2.2 The Temporal Dimension | 166 |
| 7.2.3 The Analytical Orientation Dimension | 166 |
| 7.3 DEFICIENCIES AND NEEDS OF THE EXISTING KNOWLEDGE | 167 |
| 7.4 RESEARCH QUESTIONS | 169 |
| 7.4.1 Morphology | 169 |
| 7.4.2 Production Mode | 170 |
| 7.4.3 Function/Use/Damage | 170 |
| 7.4.4 Recycle/Curation/Disposal | 171 |
| 7.5 DATA NEEDS | 171 |

TABLE OF CONTENTS (CONTINUED)

| | <u>Page</u> |
|--|-------------|
| 8.0 SETTLEMENT PATTERNS RESEARCH DOMAIN | 173 |
| 8.1 CONSTRAINING RESOURCES | 174 |
| 8.1.1 Water | 174 |
| 8.1.2 Food | 175 |
| 8.1.3 Fuel | 175 |
| 8.1.4 Shelter | 176 |
| 8.2 GEOMORPHIC VARIABLES AND ALTERNATIVE LAND-USE PATTERNS . . | 176 |
| 8.3 ETHNOGRAPHIC AND ETHNOHISTORIC ANALOGIES | 181 |
| 8.4 SYNCHRONIC MODELS FOR FORT BLISS AND THE SURROUNDING AREA | 187 |
| 8.5 ADAPTIVE DIVERSITY - ALTERNATIVE EXPLANATIONS | 191 |
| 8.6 RESEARCH QUESTIONS | 192 |
| 8.6.1 Questions at a Geomorphic Scale | 193 |
| 8.6.1.1 Central Basin Playas | 193 |
| 8.6.1.2 Basin Floor | 193 |
| 8.6.1.3 Alluvial Fans | 193 |
| 8.6.1.4 Otero Mesa | 194 |
| 8.6.1.5 Uplands | 194 |
| 8.6.1.6 Riverine Zone | 195 |
| 8.6.2 Questions at the Site or Intersite Scale | 195 |
| 8.6.3 Questions at the Intrasite Scale | 196 |
| 9.0 SUBSISTENCE RESEARCH DOMAIN | 197 |
| 9.1 APPROACHES TO SUBSISTENCE ISSUES | 197 |
| 9.2 BIOLOGICAL DATA | 199 |
| 9.2.1 Coprolites | 199 |
| 9.2.2 Flotation | 199 |
| 9.2.3 Pollen | 202 |
| 9.2.4 Phytoliths | 203 |
| 9.2.5 Faunal Remains | 204 |
| 9.2.6 Isotope Signatures in Bone Collagen | 205 |
| 9.2.7 Residue Analysis | 207 |
| 9.2.8 Summary | 208 |
| 9.3 ARTIFACTUAL DATA | 208 |
| 9.3.1 Lithics | 208 |
| 9.3.1.1 Groundstone | 209 |
| 9.3.1.2 Chipped Stone | 211 |
| 9.3.2 Ceramics | 213 |
| 9.3.3 Features | 214 |
| 9.3.4 Perishable Remains | 216 |

TABLE OF CONTENTS (CONTINUED)

| | <u>Page</u> |
|---|-------------|
| 9.4 RESEARCH QUESTIONS | 216 |
| 9.4.1 Synchronic Research | 216 |
| 9.4.1.1 Central Basin Playa Zone | 217 |
| 9.4.1.2 Basin Floor | 218 |
| 9.4.1.3 Alluvial Fans | 218 |
| 9.4.1.4 Otero Mesa | 218 |
| 9.4.1.5 Uplands | 219 |
| 9.4.1.6 Riverine Zone | 219 |
| 9.4.2 Diachronic Research Issues | 220 |
| 9.4.2.1 Diachronic Trends in Natural Resource Use | 220 |
| 9.4.2.2 Changing Agricultural Dependence through Time | 221 |
| 9.5 SUMMARY | 223 |
| 10.0 CULTURAL INTERACTION RESEARCH DOMAIN | 225 |
| 10.1 CHARACTERIZATION OF RAW MATERIALS | 227 |
| 10.1.1 Petrographic Analysis | 227 |
| 10.1.2 Trace Element Analysis | 228 |
| 10.1.2.1 Optical Emission Spectrometry | 228 |
| 10.1.2.2 Inductively Coupled Plasma Emission Spectrometry | 228 |
| 10.1.2.3 Atomic Absorption Spectrometry | 228 |
| 10.1.2.4 Neutron Activation Analysis | 228 |
| 10.1.2.5 X-ray Fluorescence Spectrometry | 229 |
| 10.1.2.6 Proton Induced X-ray and Gamma-ray Emission | 229 |
| 10.1.3 Fission-track Analysis | 229 |
| 10.1.4 Mössbauer Spectroscopy | 229 |
| 10.1.5 Isotopic Analysis | 229 |
| 10.1.6 X-ray Diffraction Analysis | 230 |
| 10.2 DIACHRONIC INDICATIONS OF CULTURAL INTERACTION | 230 |
| 10.2.1 Paleoindian | 231 |
| 10.2.2 Archaic | 231 |
| 10.2.3 The Formative Period | 232 |
| 10.2.3.1 Ceramics | 232 |
| 10.2.3.2 Ornamental Objects | 236 |
| 10.2.3.3 Caches | 240 |
| 10.2.3.4 Feathers | 241 |
| 10.2.4 Summary of Formative Interaction | 242 |
| 10.2.4.1 Mesilla Phase | 242 |
| 10.2.4.2 Doña Ana Phase | 242 |
| 10.2.4.3 El Paso Phase | 243 |
| 10.2.5 Conclusions | 244 |

TABLE OF CONTENTS (CONTINUED)

| | <u>Page</u> |
|---|-------------|
| 10.3 RESEARCH QUESTIONS | 246 |
| 10.3.1 Ceramics | 246 |
| 10.3.2 Lithics | 246 |
| 10.3.3 Ornamental Objects | 247 |
| 10.3.4 Caches | 247 |
| 10.4 DATA NEEDS | 248 |
| PART III: SUMMARY | |
| 11.0 IMPLEMENTING THE RESEARCH DESIGN | 249 |
| 11.1 THE RESEARCH DESIGN AS A TOOL | 249 |
| 11.2 EXISTING SITE DATABASE | 250 |
| 11.2.1 Methodological Biases | 250 |
| 11.2.2 Geomorphic Biases | 252 |
| 11.2.3 The Relationship Between Site Size and Data Content | 254 |
| 11.2.4 Implications of the Biases | 256 |
| 11.3 STRATEGIC APPROACHES FOR MANAGING THE FORT BLISS SITE INVENTORY | 258 |
| 11.4 SUMMARY OF DATA NEEDS | 260 |
| 11.4.1 Chronometrics Domain | 260 |
| 11.4.2 Geoarcheology Domain | 260 |
| 11.4.3 Paleoenvironment Domain | 260 |
| 11.4.4 Technology Domain | 260 |
| 11.4.5 Settlement Patterns Domain | 261 |
| 11.4.6 Subsistence Domain | 261 |
| 11.4.7 Cultural Interaction Domain | 261 |
| 11.5 A MODEL FOR ASSESSING SITE SIGNIFICANCE AT FORT BLISS | 261 |
| 12.0 REFERENCES CITED | 265 |

APPENDICES

Appendix A Geoarcheological Field Form

LIST OF FIGURES

| | <u>Page</u> |
|---|-------------|
| Figure 1 Location of Fort Bliss | 2 |
| Figure 2 Major Landscape Features on Fort Bliss and Surrounding Areas | 10 |
| Figure 3 Distribution of Principal Landforms on Fort Bliss | 13 |
| Figure 4 Simplified Map of Soil Distribution on Fort Bliss | 18 |
| Figure 5 Map of the Distribution of Major Vegetation Communities on Fort Bliss | 24 |
| Figure 6 Tectonic Map of the Fort Bliss Region | 33 |
| Figure 7 Schematic Cross-section of the Southern Tularosa Basin | 34 |
| Figure 8 Generalized Cross-section of the Northern Hueco Bolson | 35 |
| Figure 9 Quaternary Stratigraphy of the Hueco and Tularosa Basins | 37 |
| Figure 10 Block Diagram Illustrating Relationships Between Morphostratigraphic Units in the Bolson | 40 |
| Figure 11 Summary of Paleoenvironmental Data from the Southern New Mexico Region | 42 |
| Figure 12 Simplified Decay-series of Uranium-235 and Uranium-238 | 62 |
| Figure 13 Flow Diagram of Organic Matter Routes Through the Soil/sediment System | 65 |
| Figure 14 Idealized Models for the Relationship Between Actual Sediment Age and Apparent (Radiocarbon) Age in a Small Catchment | 68 |
| Figure 15 Detail of a Blowout Depression Associated with a Road on Otero Mesa Containing a Lag of Ceramics and Chipped Stone | 86 |
| Figure 16 Oblique Aerial Photograph of the Bolson Floor, Illustrating the Character of Mesquite Coppice Dune Fields | 89 |
| Figure 17 Large Climbing Dune Containing Archeological Strata Developed on the Margin of a Fan-channel Arroyo, McGregor Range | 90 |
| Figure 18 Generalized Model of the Effects of Subsequent Eolian Activity on Archeological Sites | 92 |
| Figure 19 Generalized Model of the Effect of Dune Migration on Preservation of Archeological Sites Formed in an Active Eolian Environment | 93 |
| Figure 20 Generalized Model of the Effect of Renewed Eolian Activity on Archeological Sites Formed in a Stabilized Eolian Environment | 94 |
| Figure 21 Generalized Model of Artifact Dispersion by Eolian Activity | 96 |
| Figure 22 Generalized Model of Artifact Concentration by Eolian Activity | 97 |
| Figure 23 Illustration of Eolian Alteration Units | 99 |
| Figure 24 Schematic Illustration of Stratigraphic Variability Observed at a Single Archeological Site in the Northern Hueco Bolson | 100 |
| Figure 25 Illustration of an Idealized Alluvial Fan | 105 |
| Figure 26 Complex Fan-channel Deposits Exposed in an Arroyo on McGregor Range | 108 |
| Figure 27 The Nine Possible Shapes of Three-dimensional Hillslope Facets | 116 |
| Figure 28 Two Generalized, Simplified Models of Arid Zone Slope Retreat | 118 |
| Figure 29 Illustration of the Time Necessary to Reach Steady-state for Various Soil Properties | 127 |
| Figure 30 Illustration of Carbonate Stage Morphology Sequence | 129 |
| Figure 31 Trends in Carbonate and Clay Content in Alluvial Soils of South-central New Mexico | 133 |
| Figure 32 Carbon Isotope Trends from Studies of Soil Carbonate in the Fort Bliss Region | 155 |

LIST OF FIGURES (CONTINUED)

| | <u>Page</u> |
|--|-------------|
| Figure 33 Oxygen Isotope Trends from Studies of Soil Carbonate in the Fort Bliss Region . . . | 156 |
| Figure 34 Three Dimensional Matrix of Technological Components | 165 |
| Figure 35 Site Distribution, Fort Bliss Maneuver Areas 1 and 2 | 194 |
| Figure 36 Changes Over Time in Selected Agricultural Indicators Within Lowland Portions of the Study Area | 222 |
| Figure 37 Source Areas of Intrusive Ceramics During the Mesilla Phase. | 233 |
| Figure 38 Source Areas of Intrusive Ceramics During the Doña Ana Phase. | 237 |
| Figure 39 Source Areas of Intrusive Ceramics During the El Paso Phase. | 245 |
| Figure 40 Comparison of Survey Intensity for Six Fort Bliss Survey Projects | 251 |
| Figure 41 Distribution of Point Provenienced Artifacts Within a 10 HA Area, by Exposure . . | 254 |
| Figure 42 Site Area and Artifact Diversity | 256 |
| Figure 43 Cultural, Processual, and Methodological Factors Affecting Archeological Data Sets | 297 |
| Figure 44 A Model of Site Significance Evaluation for Fort Bliss | 263 |

LIST OF TABLES

| | <u>Page</u> |
|---|-------------|
| Table 1 Relative Percentages of Total Area Occupied by Various Landforms on Fort Bliss . . | 12 |
| Table 2 Summary of Principal Soil Series Occurring on Fort Bliss | 16 |
| Table 3 Flora of the Fort Bliss Region | 20 |
| Table 4 Partial List of Faunal Taxa Occurring in the Vicinity of Fort Bliss | 26 |
| Table 5 Generalized Stratigraphy of the Fort Bliss Region | 30 |
| Table 6 Summary of Cultural Periods, Phase Names, Chronological Periods, Diagnostic Artifacts, and Architectural Characteristics | 46 |
| Table 7 Quaternary Dating Methods | 58 |
| Table 8 Cosmogenic Nuclides Used for Quaternary Surface Exposure Dating | 73 |
| Table 9 Common Projectile Point Types and Their Probable Date Ranges for the Jornada Region | 78 |
| Table 10 Common Ceramic Types and their Probable Date Ranges for the Jornada Region . . | 79 |
| Table 11 Correlation of Eolian Deposits on Fort Bliss and White Sands Missile Range | 98 |
| Table 12 Classification of Mass Movements Typical of Warm Deserts | 115 |
| Table 13 Types of Proxy Data Bearing on Climate, with Representative Studies | 141 |
| Table 14 Assays Suitable for Characterization of Archaeological Materials. | 231 |
| Table 15 Intrusive Ceramic Types During the Formative. | 234 |
| Table 16 Number of Artifact Types as a Function of Site Size | 255 |
| Table 17 Number of Temporal Components and Site Size | 256 |

PART I: RESEARCH CONTEXT

1.0 INTRODUCTION/OVERVIEW

W. Nicholas Trierweiler

This document is a design for future archeological research at Fort Bliss. It reviews previous work, assesses the current body of knowledge, and develops avenues for further inquiry. This research design is intended to be a component in the management plan with which Fort Bliss can manage its cultural resources, as is required by federal law. This research design does not attempt to suggest, advocate, or restrict alternative management strategies such as preservation, avoidance, creation of districts or zones, monitoring, or mitigation of adverse impacts. These are properly the focus of the management plan. Rather, the research design identifies the kinds of scientific research which are needed to further our knowledge of regional prehistory, and suggests methodologies for filling in the "gaps" in the database.

1.1 OVERVIEW OF FORT BLISS

Fort Bliss Military Reservation is located north of the city of El Paso in extreme west Texas and south-central New Mexico (Figure 1). As one of the nation's largest military installations, it covers over 4,500 square kilometers (km)(nearly 1.1 million acres, more than 1,700 mi²), and is larger than 243 of the 254 counties in the state of Texas as well as the entire state of Rhode Island. Most maneuver areas and guided missile ranges are in New Mexico, but the major cantonment is situated in El Paso, Texas, across the border from Juarez, Mexico. El Paso-Juarez is the largest port of entry on the United States-Mexico border, and both cities are the largest border cities for their respective countries, with a combined population of more than one million.

Assigned to the United States Army Training and Doctrine Command (TRADOC), the post is home to the Air Defense Artillery (ADA) Center and the U.S. Army ADA School. The TRADOC units posted at Fort Bliss are the 6th ADA Brigade, consisting of five TRADOC battalions: 1st, 2nd,

3rd, 4th and the 1st Battalion, 56th ADA Regiment. Other TRADOC units are the Garrison Troops, the 1st Combined Arms Support Battalion (CAS), and the U.S. Army Sergeants Major Academy. The United States Forces Command (FORSCOM) units at Fort Bliss are the 108th and the 11th ADA Brigade. The mission of the ADA Center is to maintain assigned FORSCOM units at a high readiness level within available resources. The ADA Center undertakes the administration, training, and deployment of personnel from the Active Army, National Guard, Army Reserves, other Reserve Forces Act personnel, and personnel of other services and countries (Fort Bliss 1993:11). Fort Bliss is also home to the William Beaumont Army Medical Center (one of the largest in the Army), as well as several large non-Defense Department agencies such as Joint Task Force 6 and the Drug Enforcement Agencies El Paso Intelligence Center. Fort Bliss is also headquarters for the German Air Force Air Defense School, which trains thousands of German airmen each year.

1.1.1 History

The history of Fort Bliss as a military post began in 1849, when units of the 3rd Infantry commanded by Brevet Major Jefferson Van Horne were first garrisoned in El Paso at the newly formed "Post of El Paso." Abandoned in 1851, the post was reformed in a new location in 1854 with units of the 8th Infantry and was named Fort Bliss, for William Wallace Smith Bliss, a distinguished veteran of the Mexican War. The fort was a key link in the chain of forts between Santa Fe and San Antonio intended to protect the western frontier against Indians. The garrison participated in several Indian campaigns prior to the Civil War. In 1861 the post was abandoned by the then commander, Colonel Isaac Reeve, and was vacant for three months before being reoccupied by the 2nd Regiment of Texas Mounted Rifles. Fort Bliss was abandoned again after the defeat of Brigadier General Henry Sibley at the Battle of Glorieta Pass in 1862. It was reoccupied

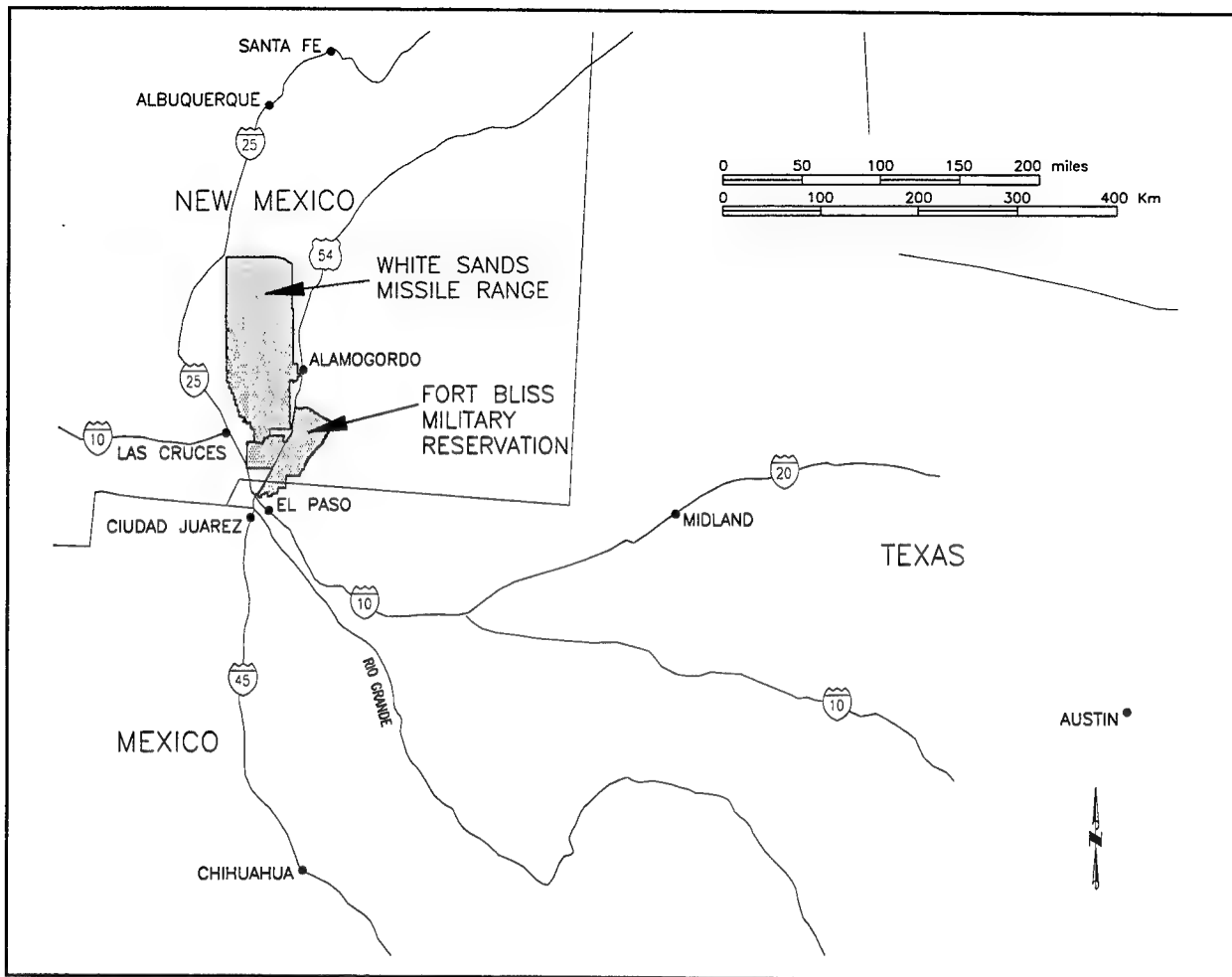


Figure 1 Location of Fort Bliss.

several months later by troops from Carylton's California Column, who kept the Union flag flying at Fort Bliss through the end of the Civil War. In 1865, the U.S. Army 5th Infantry replaced troops from the California Column who were being mustered out of the Army. A new location farther away from the Rio Grande flooding area was chosen in 1868 and temporarily named Camp Concordia. The post was again abandoned in 1877, but the military's absence allowed lawlessness to flourish, and in 1878 units of the 9th Cavalry and 15th Infantry were again posted to Fort Bliss, thus establishing the fourth location for the fort in 1879. A newly granted railroad right-of-way through the post forced the fifth and final relocation of the site in 1893.

During the Spanish American War in 1898, both the 18th Infantry and 5th Cavalry at Fort Bliss were active, and beginning in the early 1900s, both the fort and El Paso began to grow in size and importance. Following Pancho Villa's raid in 1916, General John J. Pershing led the 5th, 7th, and 10th Cavalry, the 6th and 16th Infantry, and the 4th and 6th Field Artillery across the Mexican border on a series of punitive raids.

During World War I, the fort was garrisoned by the 15th Cavalry and served a key role in training units bound for the European Theater. After the war, Fort Bliss units participated in additional actions across the Mexican border between 1919-1929. In 1919, Biggs Army Airfield was established near the intersection of Forrest and

Pleasanton Roads, moving in 1926 to its present location. Between the wars, Fort Bliss became the last bastion of the horse cavalry, but the end of the horse era came in 1943 when the 1st Cavalry Division was mechanized and sent overseas. In 1940, the Army established the first Anti-aircraft Training Center at Fort Bliss, and by the end of WWII Fort Bliss had begun its new incarnation, with the establishment of the Army's first guided missile unit in late 1945. Research at Fort Bliss quickly led to development of the Nike Ajax guided missile system, and during the Cold War, Fort Bliss was a center for the testing and training of increasingly sophisticated air defense weapons systems, including the HAWK and Patriot missile systems. By the end of the Cold War, Fort Bliss was one of the U.S. Army's premier centers for air defense training. During the Gulf War of 1990-1991, many ADA troops trained at Fort Bliss were deployed overseas. These ADA personnel were central in defeating the Iraqi SCUD missile attacks, and the 3rd Armored Cavalry regiment played a key role in the sweeping and successful ground assault against the armored Iraqi Republican Guard.

1.1.2 Archeology and Cultural Resource Management

Adolf Bandelier (1890) and J. W. Fewkes (1902), two early explorers and anthropologists, both played a part in the history of the immediate El Paso area with their descriptive archeological knowledge and ethnographic accounts of vanishing peoples and lifeways. The earliest archeological investigations in the Fort Bliss area were conducted by amateurs without much publication of work or results. These works were alluded to in reports published in the late 1920s. In 1928 C.B. and Harriet Cosgrove carried out some of the area's earliest professional work in the Hueco Mountains. They worked in a series of caves that presently lie within the Fort Bliss boundaries. The publication of that work was finally realized in 1947, almost 20 years after its completion (Cosgrove 1947). Work was carried out by Bradfield (1929), Stubbs (1930), and Sayles (1935). In 1948 Donald Lehmer published his

synthetic framework for the Jornada region. He established a phase sequence for the area; it is still in use today. A more intensive review of previous research in the area is presented in Chapter 4.0.

Relatively little work was published between the late 1940s and the 1960s. Moore and Wheat (1951) reported the discovery of a cache of pottery and associated artifacts on the old Tobin Ranch northeast of El Paso. This discovery was made in the course of survey work initiated by Mr. and Mrs. Glen E. Moore in the summer of 1936, and their survey work continued through the 1950s (Moore and Wheat 1951). Much of the work in the 1960s and 1970s was accomplished by members of the El Paso Archaeological Society, Inc. (EPAS), a very active avocational group. Many of their reports focused on the description of late formative sites of the El Paso phase. *The Artifact*, the journal of the society, represented a large proportion of the published data for the area. Today it still fills that role for both avocational and professionals working in the area. As we discuss in Chapter 4.0, the federally mandated cultural resource management needs of Fort Bliss began to enlarge the database considerably for the area through the survey work on Fort Bliss by Beckes et al. (1977), Whalen (1977, 1978), Skelton et al. (1981), and Carmichael (1986a). Through all this work, increasing emphasis on environmental, ecological, and adaptive explanations brought to light new perspectives on Lehmer's work of 1948.

Extensive archeological fieldwork has continued at Fort Bliss in order to keep up with the necessary inventory on lands that are impacted by the military as they carry out their air defense missions. Currently the Fort Bliss site files contain approximately 13,000 archeological and architectural properties; most of these have not been evaluated as to their eligibility for inclusion in the National Register of Historic Places (NRHP), as is required by federal law.

The reconnaissance and survey procedures of past work have each brought about changes in survey methodology (cf. Whalen 1977, 1978; Carmichael

1986a; Mauldin, Graves, and Bentley 1994). Each archeological project undertaken realizes new or additional information that must be incorporated in a plan allowing sites to be effectively evaluated as to their significance in accordance with Section 106 of the National Historic Preservation Act (NHPA).

In 1981 the Advisory Council on Historic Preservation, the states of New Mexico and Texas, Fort Bliss, Headquarters Training and Doctrine Command (TRADOC), and the Department of the Army signed a Memorandum of Agreement, and in 1982 a Cultural Resources Management Plan (CRMP) was ratified by the agencies noted above. By 1992 noncompliance with Section 106 of the NHPA had become an issue at Fort Bliss, and a revision of the CRMP was indicated. The SHPOs and the Advisory Council met with Fort Bliss and agreed to the development of both a Programmatic Agreement (PA) and a new preservation plan for cultural/historical resources. In January 1993 a draft of a revised PA was developed, calling for a new CRMP. In September 1993, TRC Mariah was issued a delivery order by the Army Corps of Engineers, Fort Worth District, to develop a draft CRMP for Fort Bliss. Subsequent restructuring within the Fort Bliss Directorate of Environment (DOE) and restaffing of cultural resource personnel led to a modification of the delivery order in June 1994. The revised delivery order called for TRC Mariah to develop a detailed research design for prehistoric archeological resources; concerns with historic structures were deleted, as were recommendations for policies and procedures. The Fort Bliss DOE agreed to develop the more broadly focused CRMP. As a result, the current research design is intended to be a single component of the CRMP.

1.2 PURPOSE AND SCOPE OF THE RESEARCH DESIGN

1.2.1 Requirements

The NHPA of 1966 [16 U.S.C. 470(f) and 470h-2-(f)] created the NRHP to preserve and protect important aspects of our nation's cultural and

historic heritage. The Act also created the Advisory Council on Historic Preservation (ACHP) as an implementing agency, and further mandated that each state appoint a State Historic Preservation Officer (SHPO). Under Section 106 of the Act, its implementing regulations (36 CFR 800), federal agencies, and installations (and certain other federally funded or permitted projects) must take into account the effect of any undertaking on any district, site, building, structure, or object (a "historic property") that is included in the NRHP or is eligible for inclusion. Section 110 of the Act further requires that federal agencies assume responsibility for the preservation of historic properties located on their land or controlled by them. The responsible agency must take into account the effects of their undertakings on the cultural resources at the planning stages, must provide protective measures for any affected resources, and must give the ACHP an opportunity to comment on the undertaking's effect on listed or eligible properties. To this extent, the responsible federal agency must inventory and evaluate cultural resources relative to the NRHP criteria.

As a federal agency, the U.S. Army is required to undertake a program to locate, inventory, and nominate to the Secretary of the Interior all properties owned or under the control of the Army that appear to qualify for inclusion on the NRHP. Army Regulation 420-40 prescribes Army policy, procedure, and responsibilities for carrying out the NHPA, as amended, and for managing the preservation requirements at the installation level through development and implementation of a Historic Preservation Plan (HPP) or a CRMP. The Regulation prescribes professional standards for Army preservation personnel and projects and for accomplishing the historic preservation program in a timely and cost-effective manner.

In order to comply with the NHPA and AR 420-40, the HPP/CRMP must (1) develop explicit procedures that allow for the identification of all cultural resources under the installation's jurisdiction, and (2) develop explicit standards of significance that allow for their evaluation with respect to NRHP eligibility. For archeological

properties, such standards are generally developed in a scientific research design.

1.2.2 Development of Significance Standards

This section offers a brief overview of the process through which scientific research designs are developed and used as mechanisms for assessing the significance of cultural resources on military reservations. The discussion is broadly adapted from an earlier research design (Trierweiler 1994); the reader already familiar with these issues may choose to skip this section.

1.2.2.1 The Nature of Research Designs

As defined by Section 106 and its implementing regulations, the "significance" of any given cultural resource cannot be determined idiosyncratically. Significance must be assessed by rigorously comparing the property to currently accepted standards of research value. Developing such standards is one function of the research design. The research design identifies specific topics that should be addressed by future research. Because modern installation boundaries seldom coincide with historically or prehistorically meaningful territories, research designs usually consider the broader region beyond the boundaries of the installation itself.

Research designs vary tremendously in scope and complexity, depending on the project parameters (e.g., size and configuration of the study area), but all fundamentally consist of a set of questions and a set of methods needed to obtain reliable answers. Not all research designs are scientific. Nonscientific research is idiosyncratic and nonreplicable: any conclusions rely on the weight of the researcher's opinions for credibility. By contrast, scientific research sets up experiments and uses data to reach conclusions. In this regard, research designs are rigorous and replicable, and conclusions may be critically examined by other researchers.

In any scientific research design, the questions must be interesting, or *problematic*. This is

because not all research questions are necessarily equivalent in importance; some may be trivial and others may have been adequately answered long ago; other questions remain problematic despite active investigation; still other questions arise with each new advance in theory and method. Well-documented topics, or those that are uninteresting or trivial, are not targeted by research questions. Problematic research questions are derived from recognized gaps in a current body of scientific knowledge. In cultural sciences, such as archeology, these bodies of knowledge may be highly regional; gaps in one state, or even county, may be well covered in an adjoining region. These so-called "data gaps" are topics for which there is insufficient information to draw reliable conclusions. Some gaps may be due to a lack of previous research on the topic. Other gaps may be recognized because the previous research is considered inadequate or outdated. Data gaps can also result simply from scanty information on the topic despite previous intensive and excellent research efforts.

To be useful, a research design must associate each question with the specific data needed to answer the question. Data requirements must be spelled out so that the field work will be sure to collect these kinds of data (if they are available). Often, the same type of data may be simultaneously needed to answer more than one question.

1.2.2.2 Using Research Designs

Under Section 110 of the NHPA, a cultural resources management program must identify *significant* historic properties so that they can be managed through avoidance and protection. Broadly, those properties that meet many of the data requirements stipulated in the research design are judged to be significant, whereas those that meet few of them are judged not significant. In practice, the CRM compliance process at military installations is often implemented using four largely sequential steps:

- (1) *developing* standards of significance (most often in a research design),
- (2) *finding and evaluating* the resources, and
- (3a) *preserving and protecting* those judged to be significant, or
- (3b) *mitigating damage* if some or all historic properties cannot be protected.

These components are sometimes operationalized into discrete work phases, but there is often considerable overlap between process components. Indeed, the larger the study area (as Fort Bliss), the greater the number of properties, and the more complicated the process can become.

Ideally, properties should be evaluated for significance as soon as possible upon their discovery; determining significance should not necessarily be postponed until a later formalized testing phase. Indeed, the significance of any property can (at least, theoretically) be determined by means of a single, well-planned field visit. In practice, however, the full assessment of significance for some properties must proceed through additional work phases. This is primarily for economic reasons: different kinds of properties require widely varying levels of investigation to reach the same significance assessment, and it is usually more cost-effective to conduct the fieldwork in a staged approach. In cultural resources management, the two sequential and complementary phases of significance evaluation are most often referred to as "inventory" and "testing," though other terminologies are sometimes used. Each phase focuses on a prioritized hierarchy of data requirements.

During an inventory phase, cultural resources are first identified and then observations of data potential are made to allow a significance assessment (if possible). At Fort Bliss, the kinds of observations made during the inventory phase have been generally *limited to the surface of the site*. While some sites have been fully assessed in

this manner, most sites have required additional field effort over that typically expended during this phase; in many cases, significance may not be determined in the absence of subsurface data. Based on inventory phase observations, three outcomes are possible in assessing significance: (1) Some properties may have no potential with which to address the data gaps; no further management action is warranted. (2) Some properties may have clear research potential; these must be preserved and protected or mitigated. (3) Finally, for some properties, the limited kinds of observations that are possible during the inventory will not permit a full evaluation of data potential; these properties must be further "tested" to determine their data potential and significance. In the last outcome, additional field work is usually necessary because the additional observations needed to test the property often require detailed subsurface excavations.

From the perspective of the cultural resources manager, there is an economic trade-off between investing effort in inventory and testing. A greater effort expended during inventory will certainly require greater up-front funding but may well allow significance evaluation of a greater proportion of all sites. For example, inventories that include subsurface evaluation (geomorphology and/or shovel testing) will generally evaluate a greater proportion of sites than similar inventories without subsurface evaluation. Conversely, a lower level of effort expended during the inventory phase may well be cheaper initially, but this option will almost certainly require that more sites receive the labor intensive test excavations at a later point. In general, it is often more cost-effective in the long run to conduct a higher level of effort during the inventory phase in an attempt to fully evaluate as many sites as possible and reduce the pool of sites that must be formally tested.

1.2.3 Limitations of this Research Design

This research design develops a framework for further scientific inquiry. It reviews existing knowledge, identifies data gaps, and delineates

important research questions and their data needs. Within the context of a CRMP, these data needs may be applied as standards for site "significance" and, hence, NRHP eligibility. However, the research design itself does *not* develop policies nor procedures for integrating the scientific inquiries within the military mission; this is properly the function of a CRMP. This distinction is further discussed in Chapter 12.0.

This research design develops contexts for the evaluation of prehistoric archeological resources only. Historic archeological resources are not included in its scope, nor are historic architectural resources. Significance standards for these types of resources must be developed by other sets of contexts.

This research design is intended to be a working (i.e., active) structure within which to organize and focus archeological research. Although based on published and currently available (1995) information, it is not intended to be static nor permanent. As ongoing research is published and as new research is completed, it is likely that some of the research questions posed herein may be satisfactorily answered, and that new avenues of research will be identified. Therefore, it should be assumed that this research design will need periodic review and revision.

1.2.4 Theoretical Orientation

The broadest theoretical stance taken in this research design is explicitly materialistic with a rational-functional approach to explaining human behavior. That is, material explanations are sought for human behavior, as opposed to ideational, humanistic, or other nonscientific sources. The basic approach follows that of Harris (1979). This theoretical stance acknowledges the value of non-material insights into human behavior, but argues that such approaches can not be consistently nor productively applied as explanatory frameworks.

The research design also implicitly adopts a systems theory approach. Human societies are

considered to be intricate systems of variables with ever-changing relationships between those variables (Buckley 1968). Understanding the dynamics of these relationships is key to explanations of culture change. Explanations of human culture can be as robust or as flimsy, as sweeping or as circumscribed as the rigor used in identifying and measuring the important variables and relationships.

The third leg in the theoretical triad supporting this research design is cultural ecology. The cultural ecological approach examines the interactions between people and their surrounding natural and cultural environments, and attempts to identify the adaptive strategies by which societies survive, and flourish, within the constraints set by their environments (Vayda and Rappaport 1968). This "cultural-ecosystem" view explicitly acknowledges the interactive effects that human cultures have on their environments, as well as the obverse (Butzer 1982). Within the cultural ecological approach, a key theoretical subtext in this research design is economic optimization (Keene 1979). Based on the assumption of rationality, and incorporating classic micro-economic modeling, economic optimization presumes that human societies tend to identify and select those sets of behaviors (survival strategies) with the maximum net utility. Profitable behaviors are those which satisfy system needs (e.g., food and protection) at a lower cost (e.g., time and energy) than alternatives.

1.2.5 Structure of the Research Design

This document is broadly structured in three parts. Part I presents a series of background discussions as a research context. Following this introduction, Chapter 2.0 reviews the Fort Bliss study area in some detail and develops natural contexts for the research. Separate discussions review the climate, geology, physiography, biology, and hydrology of the study area. Building on the natural context, Chapter 3.0 introduces the dimension of time. The chapter begins with a detailed history of archeological research within the region from the initial reconnaissance through more recent model

building and synthetic studies and concludes with a critical review of current understanding of local culture history constructs.

Part II is the heart of the research design, developing seven individual domains for research. While recognizing the complexity of cultural systems and the ways in which humans interact with their environment, this section nonetheless adopts a fairly traditional and conservative delineation of research domains. Seven domains are presented in separate chapters. Our systems theory approach acknowledges the intensive cross-linking between the research domains (i.e., as exists between "technology" and subsistence") and we accept the fact that any delineation of domains is arbitrary. The suggested structure of research domains is intended to *facilitate* research within a practical archeological research framework, and not to *explain* cultural dynamics or cultural change. Three research domains dealing with natural contexts are presented in Chapters 4.0, 5.0, and 6.0: chronometrics, geoarcheology, and paleoenvironment. These are followed in Chapters 7.0 through 10.0 by four cultural context domains: technology, settlement patterns, subsistence, and cultural interaction. Each of these chapters presents background discussions, including theory and models, and identifies data gaps in the existing knowledge of Fort Bliss prehistory. Each chapter concludes with development of a series of specific research questions, followed by a statement of data requirements. The reader may note that several of the natural context research domains include background discussions in greater depth and detail than are normally found in comparable archeological research designs. These expanded background discussions are intended as a partial remedy for the largely absent concerns with natural context that have characterized many, though not all, of previous archeological studies at Fort Bliss.

Part III concludes the research design. This part consists of Chapter 11.0, which discusses several issues relevant to implementing the research design and then reviews and summarizes the individual research questions and the data needs. As a

cautionary discussion against simply matching the data needs against recorded data content for previously recorded sites, this chapter reviews the existing site database, with special attention paid to several fundamental problems and methodological biases that may affect data reliability. The unavoidable effects of geomorphic biases as well as those resulting from the varying intensities of previous surveys are discussed, and the implications these have on conclusions of site size and site data content are reviewed. For the extensive portions of Fort Bliss that have not yet been inventoried, sampling is then discussed as a strategy. The final section in this chapter consists of a synthesis of the research domains and a review of the research questions and data needs developed in Chapters 4.0 through 10.0. Finally, based on the data gaps identified in Chapters 4.0 through 10.0, a preliminary model for evaluating site significance is developed.

2.0 NATURAL ENVIRONMENT

James T. Abbott

This chapter summarizes the modern character and historical development of the natural environment in the vicinity of Fort Bliss. It sets the stage for the discussions in Chapters 2.0 and 3.0 of human adaptations to the environment and the natural processes affecting the preservation and integrity of the cultural record.

2.1 PHYSIOGRAPHY

The general area of Fort Bliss is considered part of the Basin and Range province, which extends in an arc from Trans-Pecos Texas, southern New Mexico, and northern Chihuahua westward into Arizona and southeastern California, then northward between the Sierra Nevada and Rockies through Nevada, northeastern California, and western Utah into southern Oregon and Idaho (Fenneman 1931; Thornbury 1965; Hunt 1967). The Basin and Range province represents an area where the continental crust has been stretched, resulting in widespread normal faulting (Peterson 1981). Fort Bliss proper is situated entirely in the Mexican Highlands Section (Bolson Subsection) of the Basin and Range province, while McGregor Guided Missile Range extends northeast into the Sacramento Section of the Basin and Range (Thornbury 1965; Hawley 1975). The region is characterized by north-south trending, block-faulted mountain ranges separated by linear, graben-defined basins. These structural basins, or *bolsons* (Tight 1905), formed closed, internally drained sediment traps that were the site of tremendous deposition from the flanking ranges during the Cenozoic period. Although drainage is now partially integrated by the through-flowing Rio Grande River and its tributaries, several of the basins (including the Tularosa Basin, which is occupied by a large portion of Fort Bliss) remain internally drained.

Principal landforms on and near Fort Bliss include the Tularosa and Hueco Basins, which represent two contiguous graben valleys underlain by thick

Cenozoic sediments, and a variety of block-faulted mountain ranges and highlands flanking the valley floors (Figure 2). Occasionally, the Tularosa basin is treated as part of the Hueco Bolson (e.g., Strain 1971); however, the two basins are structurally distinct (Collins and Raney 1991; Lozinsky and Bauer 1991) and should be considered separate entities. The valley formed by these grabens are flanked by ranges composed of horsts completely interdigitated with intrusive igneous rocks. Principal ranges flanking the basins include the Franklin, Juarez, Organ, and San Andres mountains to the west, and the Hueco Mountains, Sacramento Mountains, and Otero Mesa to the east. Another series of graben valleys, including the Jornada del Muerto and Mesilla (or La Mesa) Bolson, is present east of the Franklin/Organ/San Andres Mountain chain. Here, the Rio Grande River has entrenched up to 100 m into the bolson floors, forming the Mesilla Valley. The Rio Grande follows a series of north-south oriented, normal *en echelon* faults termed the Rio Grande Rift through south-central Colorado and north-central New Mexico before entering the Basin and Range Province in central New Mexico (Chapin and Seager 1975; Callendar et al. 1989). Although distinctive in its northern extent, the Rio Grande Rift is structurally related to the broader Basin and Range system and is not physiographically distinguishable from other graben valleys in the south (Baldrige et al. 1984); however, basins associated with the Rio Grande rift are generally deeper than surrounding basins (Seager and Morgan 1979). South of Fort Bliss, the Rio Grande enters the Hueco Bolson in the gap between the Franklin and Juarez mountains (Paseo del Norte). Here, too, the river has entrenched deeply into the Bolson floor, forming a series of stepped terraces in the El Paso Valley (Kottlowski 1958; Hawley 1965). At present, the Rio Grande is incised from 60 to 150 m (200 to 500 ft) below the bolson floor. The portion of Fort Bliss in the Hueco Bolson occupies the unentrenched northern part of the basin, and has no through-flowing trunk stream.

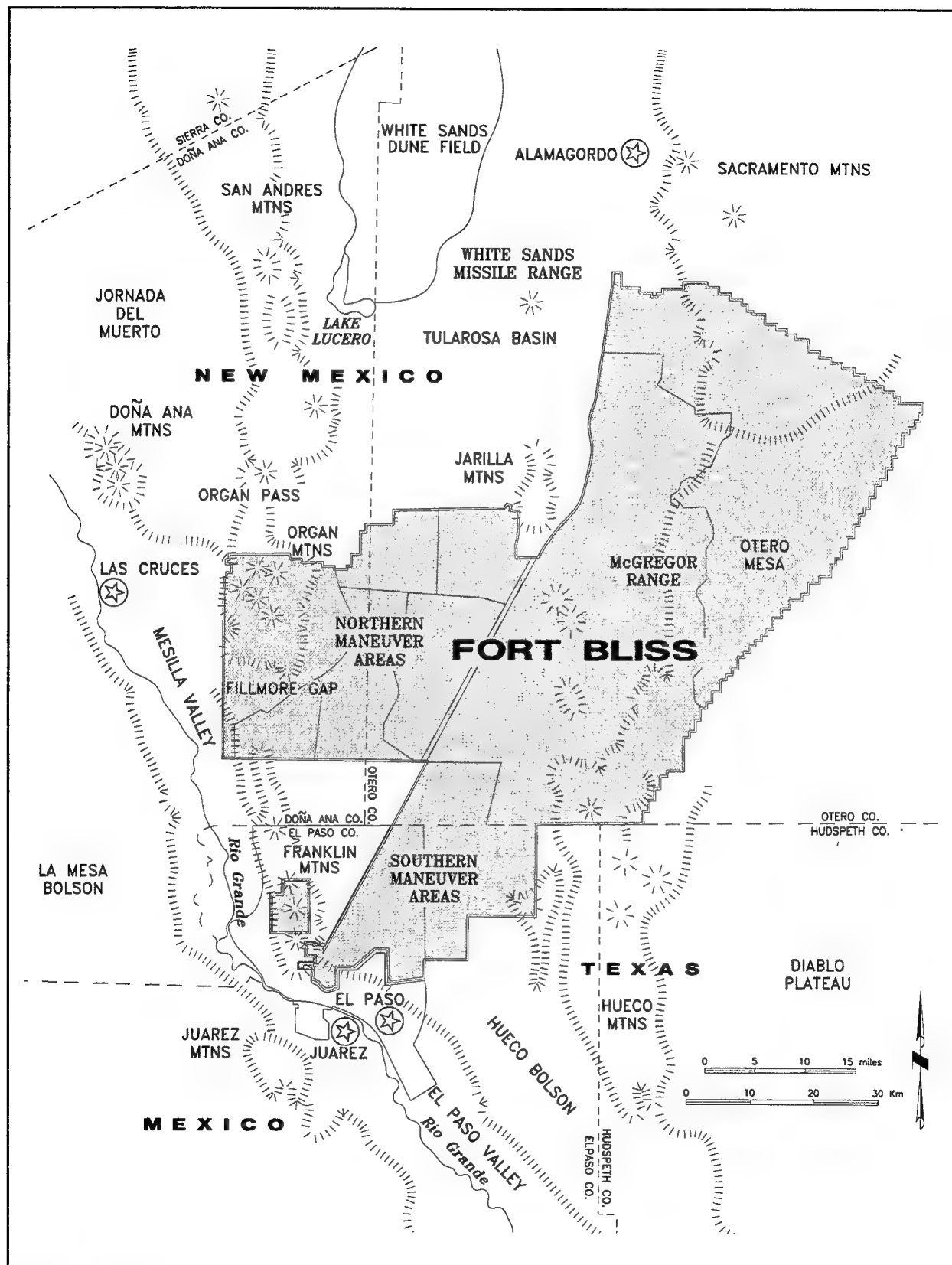


Figure 2 Major Landscape Features on Fort Bliss and Surrounding Areas.

The Franklin, Organ, and San Andres mountains border the western side of the Tularosa/Hueco Basin. Each of these ranges represent complex normal faulting and smaller scale thrust faulting of westward-dipping Precambrian and Paleozoic rocks, with some outcrops of later Cretaceous age strata and intrusive igneous rocks of Tertiary age. On the eastern side of the Tularosa/Hueco Valley, the Hueco Mountains, Otero Mesa, and the Sacramento Mountains rise abruptly from the basin floor. The Sacramento and Hueco ranges also represent relatively complex block faulting, but dip primarily to the east. Otero Mesa, which lies between the Sacramento and Hueco ranges, also dips gently to the east, but exhibits no complex internal faulting. To the east, the Hueco Mountains and Otero Mesa merge into the elevated Diablo Plateau. The eastern side of the Tularosa Valley and the northeastern side of the Hueco Bolson represent the boundary between the Mexican Highlands Section and Sacramento Section of the Basin and Range Province (Hawley 1975).

The Tularosa and Hueco Basins form a continuous valley that is oriented primarily north-south in the more northerly Tularosa Basin and turns northwest-southeast in the Hueco Basin. The divide between the two basins consists of a subtle topographic rise. Intrusive igneous rocks related to the Laramide Orogeny protrude above the basin floor in places. Notable intrusives include the Jarilla Mountains in the southern Tularosa Basin and the rocks of Hueco Tanks State Park in the northeast Hueco Bolson. Small fault block hills are common on the margin of the valleys. However, the basins are dominated by broad, gently sloping alluvial fans and fan piedmonts that spread out from the surrounding mountains and flat, dune-mantled basin floors broken by numerous small extant and relict playas. North of Fort Bliss, the extensive gypsum sand deposits of White Sands National Monument and White Sands Missile Range spread out north and northeast of Lake Lucero over the site of pluvial Lake Otero; however, the sand dunes and sheets within the boundary of Fort Bliss are essentially all siliceous. The mountains on the flanks of the valleys are

characterized by steep, rugged slopes mantled by variable amounts of scree and colluvium. Otero Mesa consists of a gently sloping, undulating surface mantled with variable amounts of fine surficial sediment. Elevations on Fort Bliss range from approximately 1,200 m (3,900 ft) in the cantonment area, which is situated on and just above the uppermost terraces of the Rio Grande River, to approximately 2,690 m (8,829 ft) in the Organ Mountains.

Satterwhite and Ehlen (1980) identify four principal landform units, which they subdivide into a series of 13 landform map units distinguishable on and mappable from aerial photographs (Table 1). The mountain unit includes subunits that encompass (1) the relatively smooth, eastward-sloping surface of Otero Mesa; (2) dissected hills formed primarily on sedimentary rocks in the Hueco Mountains, along the Otero Mesa escarpment, in parts of the southern Sacramento Mountains, and on the margins of the Franklin, Jarilla, and Organ mountains; and (3) rugged, sharp-crested mountains typically developed on jointed intrusive igneous rocks, which make up most of the Organ and Jarilla mountains, parts of the Franklin Mountains, and occasional isolated landforms along the eastern margin of the basins.

The Alluvial Fan landscape unit is subdivided into six subunits: (1) primary, high-elevation fans, which are dominantly gravelly, moderately to strongly dissected, situated near the mountain front, and typified by channeled, bypassing drainage; (2) secondary, high-elevation fans, which are also dissected, gravelly, characterized by bypassing drainage, and situated near the mountain front, but are lower and more areally restricted than the preceding class; (3) mottled, intermediate elevation fans, which occur basinward of the higher fans and are typified by finer deposits, less dissection, and dendritic distributary drainage; (4) dark-toned, low-elevation fan/aprons that grade into the basin floor, are fine-grained, show little dissection, and exhibit marked distributary drainage; (5) fans covered with eolian sands; and (6) high-elevation, anomalous fans, which occur primarily as gravelly, low-gradient,

Table 1 Relative Percentages of Total Area Occupied by Various Landforms on Fort Bliss.

| Unit | Subunit | Percentage Cover |
|-----------------|---------------------------------------|------------------|
| Mountains/Hills | Mesa | 15.8 |
| | Highly Dissected Hills | 16.1 |
| | Rugged, Sharp-Crested Mountains | 2.3 |
| Alluvial Fans | Primary High-Elevation Fans | 10.8 |
| | Secondary High-Elevation Fans | 1.2 |
| | Mottled, Intermediate-Elevation Fans | 6.8 |
| | Dark-toned, Low-Elevation Fans | 3.6 |
| | Fans Covered with Deep Eolian Sand | 3.5 |
| | High-elevation, Anomalous Fans | 0.7 |
| Basin Areas | Light-toned, Speckled Sand Dunes | 30.2 |
| | Dark-toned, Rough-textured Sand Dunes | 2.6 |
| | Low, Smooth Areas | 2.5 |
| | Small, Dark-toned Depressions | 1.5 |
| Washes | | 2.0 |

After Satterwhite and Ehlen 1980.

south-trending fans originating in the southern Sacramento Mountains and aggrading on Otero Mesa close to the mountain front.

The Basin landscape unit is subdivided into four subunits: (1) light-toned, speckled sand dunes, which represents areas dominated by mesquite coppice dunes and covers the majority of the basin floor; (2) dark-toned, rough-textured sand dunes representing larger dunes, and concentrated on the eastern side of the bolson adjacent to the distal fans; (3) low, smooth areas, consisting of level, low-lying areas (probably largely dry playas); and (4) small, irregularly dark-toned depressions, often with light-colored margins (which also probably represent basin playas).

The Wash landscape unit is not subdivided, but includes U- and V-shaped gullies on the uplands and upper fans; deeper, rectilinear-shaped arroyos on the proximal and medial fans; and shallow, broad, dendritic distributaries on the lower fan surfaces. Appreciable channels are essentially unknown on the basin floor.

An alternative subdivision of the landscape is presented in Figure 3. Here, four basic landscape elements are also identified. The upland unit encompasses the steep, rocky terrain in the Sacramento, Hueco, and Organ mountains, and some broken terrain below Otero Mesa. The Otero Mesa unit provides a useful division between the gently sloping mesa surface and the rugged mountains, which are grouped in the Satterwhite and Ehlen classification. The Proximal-Medial Alluvial Fan unit encompasses the steeper, higher elevation fans and the erosional slopes of Otero Mesa escarpment; it includes portions of the upland, fan, and wash units of Satterwhite and Ehlen (1980). Finally, the Basin Floor-Distal Alluvial Fan unit encompasses the lowest parts of the landscape, including the level basin floor and gently sloping bajada; it includes portions of the Basin, Alluvial Fan, and Wash units of Satterwhite and Ehlen (1980).

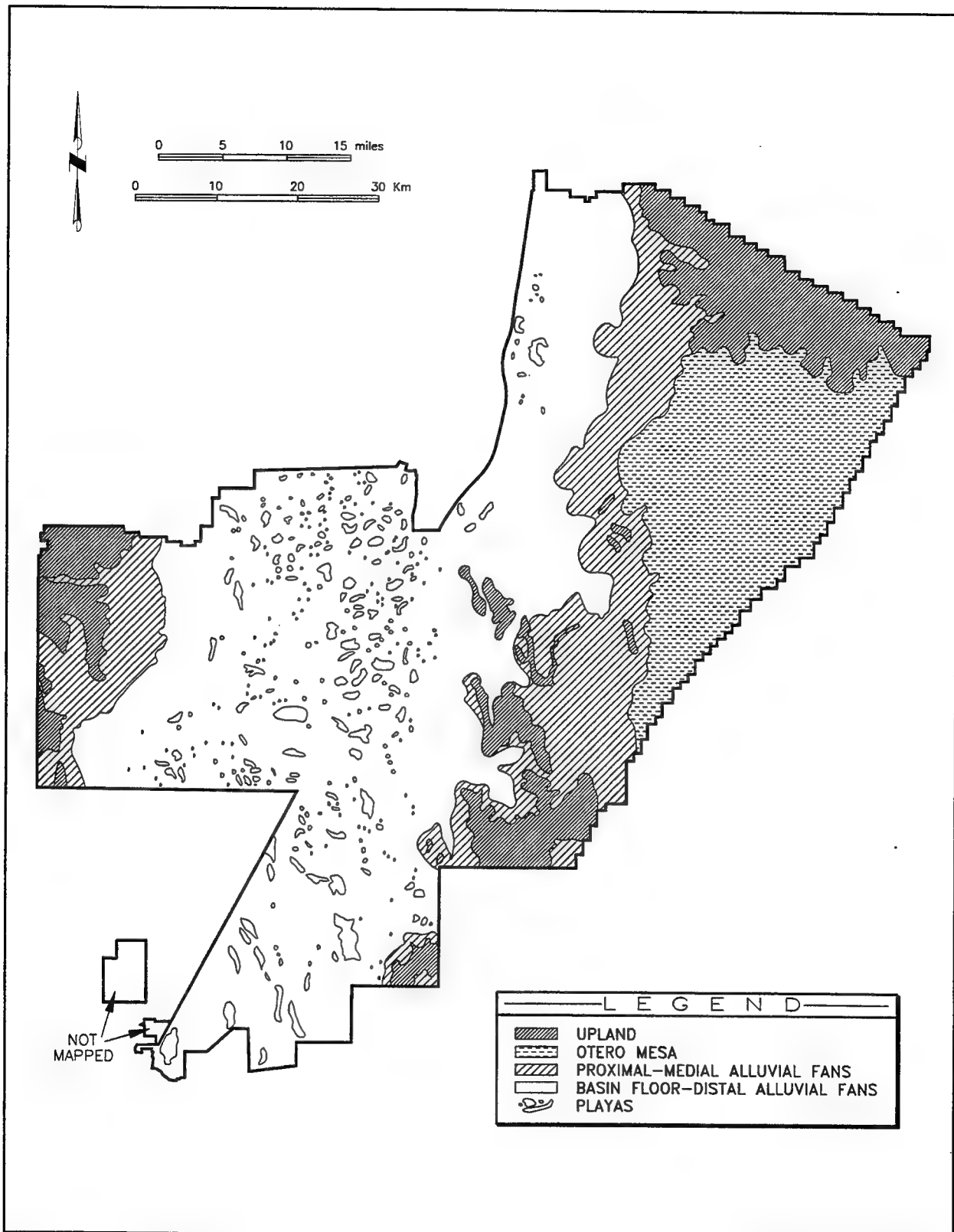


Figure 3 Distribution of Principal Landforms on Fort Bliss. Modified from the Fort Bliss GRASS System.

2.2 MODERN CLIMATE

The modern climate of Fort Bliss varies from semiarid in the highest areas of the post (e.g., the Sacramento and Organ mountains) to arid in the Tularosa and Hueco Basins. The region is characterized by long, hot summers and relatively short, mild-to-moderately cold winters (Weather Bureau 1964). All of the long instrumental records in the immediate vicinity are from stations situated at low altitude; consequently, the characterizations of the highland portions of the post in the following summary are necessarily more generalized.

Temperature typically exhibits large diurnal and annual variability. At El Paso, on the southern end of the reservation, mean high temperature in July is 94°F (34°C), while mean low temperature in January is 32°F (0°C). At Alamogordo, north of the reservation, mean high temperature in July is 95°F (35°C) and mean low temperature in January is 27°F (-3°C). Recorded temperature extremes at El Paso are 114°F (46°C) (Jim Bowman, personal communication, 1996) and -8°F (-22°C) (Kingston 1986), while a high of 116°F (47°C) was recorded at Orogrande, and a low of -16°F (-27°C) was recorded at Alamogordo (Derr 1981). In both locations, most years have at least one day above 105°F (41°C) in summer and below 10°F (-12°C) in winter, while typical diurnal variation is on the order of 26-29°F (14-16°C) in winter and 24-30°F (13-17°C) in summer. Temperatures in the mountains are only slightly cooler in the summer, but may be significantly cooler in winter due to the elevation difference.

Average annual precipitation is low, and occurs primarily in the form of thunderstorms from late summer through early autumn. Average annual precipitation at El Paso is under eight inches (195 mm), while at Alamogordo it is approximately 10 inches (254 mm) (Jaco 1971; Derr 1981). Recorded annual precipitation extremes at El Paso range from 2.2 inches (56 mm) in 1891 to 18.3 inches (465 mm) in 1884 (Jaco 1971), while over 22 inches (560 mm) was recorded at Orogrande in

1934. Over 65% of precipitation in El Paso and 66% in Alamogordo occurs as brief, heavy thunderstorms in June through October. Most of this precipitation falls so rapidly that it cannot effectively infiltrate, and brief, high-energy runoff is commonly associated with these storms. Measurable snowfall occurs in the basin occasionally, but rarely exceeds 1 to 2 inches or lasts on the ground more than 24 hours. In the higher mountains, annual precipitation is approximately 12 to 18 inches, and proportionally more of the precipitation occurs as snow in winter. Annual snowfall is on the order of 3 to 5 inches in the basin and 12 to 25 inches at high elevations.

Convective storms in the summer reflect moisture originating over the Gulf of Mexico, while winter precipitation reflects easterly moving cyclonic storms originating over the Pacific. Because the study area is situated on the lee side of the mountains in western New Mexico, little of this winter moisture penetrates as far inland as Fort Bliss. Cloudiness is low, and over 80% of the possible sunlight reaches the ground on an annual basis (Derr 1981). Relative humidity averages approximately 30% during the day, but increases to over 70% at night due to the high diurnal variability in temperature. Potential evapotranspiration is roughly 10 to 12 times annual precipitation, and is enhanced by light but sustained winds that prevails during most of the year. Although winds from the north, west, and south are common, the strongest winds originate almost entirely from the southwest and west, and are most common during the spring (McKee 1966).

2.3 SOILS

In general, the characteristics of soils reflect the combination of five soil forming factors: climate, organisms, relief, parent material, and time (Jenny 1941). The soils on Fort Bliss are no exception. Three of the 11 principal soil orders recognized by the U.S. Soil Conservation Service are mapped on the post; all three of these soil orders (Aridisols, Mollisols, and Entisols) reflect the influence of the arid climate to varying degrees. Aridisols are

classic well-developed, low-moisture soils, and occur on most of the older geomorphic surfaces. Entisols in the study area also typically reflect arid conditions, but are dominated by weak profiles resulting from a relatively short duration of pedogenesis. Mollisols in the project area typically resemble aridisols, but have a base-enriched surface horizon (mollic epipedon); they are typical of older surfaces and of higher elevations in the Sacramento and Organ mountains.

Relief and parent material also exercise strong controls on the morphology of soils in the vicinity of Fort Bliss. Typically, soils developed on high-relief slopes tend to be shallow and stony, while deeper soils are characteristic of relatively gently sloping surfaces. Parent material is responsible for many of the morphological distinctions between different soil series in similar landscape contexts. These differences may arise from variations in the texture (e.g., gravelly vs. loamy) or in the chemistry and/or mineralogy (e.g., igneous alluvium vs calcareous alluvium) of parent sediments. Finally, the degree of soil development is strongly controlled by the duration of pedogenesis, such that young soils exhibit weak profiles (e.g., weak horizonation, preserved primary stratification, cambic or absent B horizons, pre-stage I to early stage II carbonate morphology) while successively older soils show increasingly strong profiles (e.g., strong horizonation, strong cambic to argillic B horizons, late stage II to stage V carbonate morphology).

Table 2 presents the USDA Soil Taxonomy classification to the subgroup level (after Soil Survey Staff 1975; 1990) and the typical landscape context, parent material, profile, and depth of the most common soil series occurring on Fort Bliss. Note that the horizon designations do not precisely match those published in the relevant soil surveys (Derr 1981; Jaco 1971) because they have been modified to reflect the use of the *K* horizon designator (rather than the older *Ccam* horizon designator) to describe master horizons plugged by precipitated carbonate (Gile et al. 1981; Birkeland 1984; 1985) and the subordinate descriptors *y*

(rather than *cs*) for accumulation of gypsum and *k* (rather than *ca*) for accumulation of calcium carbonate.

Where individual soil series are intricately interdigitated on the landscape, or where the perceived need for detail is not great, soil mapping is typically based on soil associations, which are spatially related groups of morphologically distinct soils (Soil Survey Staff 1951). For both of these reasons, this approach was followed by the SCS in the vicinity of Fort Bliss. Figure 4 presents a simplified soil map of Fort Bliss, based on the computerized version of USDA Soil Conservation Service soil association maps compiled in the Fort Bliss GRASS (GIS) system. For reasons of clarity, the 51 soil associations on the original map have been reduced to five basic map units, which are described below:

Map Unit 1 encompasses soil associations typical of dominantly erosional upland areas, including thin soils developed on colluvium and scree. Dominant soil associations comprising this map unit include Lozier-rock outcrop complex 0% to 5% slopes and Lozier-rock outcrop complex 5% to 20% slopes in the Hueco Mountains and on the flanks of Otero Mesa; Lozier-rock outcrop complex 5% to 20% slopes, Deama-rock outcrop complex 20% to 50% slopes, and Ector-rock outcrop complex 20% to 50% slopes in the Sacramento Mountains; and igneous rock land, limestone rockland-Lozier complex, and rock outcrop-Argid association in the Organ and Franklin mountains. Most of these soils are Entisols or thin lithic Mollisols.

Map Unit 2 encompasses soil associations typical of older, higher alluvial fans and associated older eolian deposits. Petrocalcic and/or argillic horizons are common, and less-developed soils may occur locally. Dominant soil associations in Map Unit 2 include Philder very fine sandy loam 0 to 9% slopes, Armesa very fine sandy loam 0 to 5% slopes, Reyab-Armesa association, gently sloping, and Philder-Armesa association, undulating, on Otero Mesa; the Nickel-Tencee-Simona complex on the western flanks of the

Table 2 Summary of Principal Soil Series Occurring on Fort Bliss*.

| SOIL ORDER Series Name | Subgroup | Typical Landscape Context | Parent Material | Typical Profile | Depth to Subsoil (cm) |
|---------------------------|---------------------------------|---|--|-------------------------------------|-----------------------------|
| ARIDISOLS | | | | | |
| Agustin | Typic Camborthids | alluvial fans and fan channels | gravelly alluvium | A1-B2-C | 76 |
| Armesa | Ustollic Calciorthids | old alluvial fans and terraces | medium-textured, calcareous alluvium and eolian deposits | A1-B21-B22k-C1k-C2k-C3k | 36 |
| Berino | Typic Haplargids | sandy bajada/basin floor surfaces | medium-textured, calcareous alluvium and eolian deposits | A1-B21t-B22t-B23tk-Ck | 91 |
| Caliza | Typic Calciorthids | upland, older fan | noncalcareous alluvium | A-K | 20 |
| Coxwell | Ustollic Haplargids | upland pediment | igneous bedrock | A1-B1t-B2t-B3tk-R1tk-R | 20 |
| Delnorte | Typic Paleorthids | colluvial toeslopes and fans | gravelly alluvium | A1-C1k-K1-C2 | 15 |
| Doña Ana | Typic Haplargids | sandy bajada/basin floor surfaces | distal alluvial fan and eolian deposits | A1-B21tk-B22tk-B23tk-C1k-C2k | 53 |
| Hueco | Petrocalcic Paleargids | older alluvial fans | loamy fan alluvium | A1-B21t-B22t-K1-C | 66 |
| Mimbres | Typic Camborthids | distal alluvial fan/bajada/basin floor | silty calcareous alluvial sediment | A1-B21-B22-C1k-C2k | 64 |
| Nickel | Typic Calciorthids | relatively old alluvial fans | gravelly limestone fan alluvium | A1-C1-C2k-C3 | 13 |
| Nolam | Ustollic Haplargids | older alluvial fan | gravelly alluvium | A2k-B2tk-K2-K3-Ck | 28 |
| Onite | Typic Haplargids | alluvial fan | mixed alluvium | A1-B21t-B22t-C1-C2k | 76 |
| Pajarito | Typic Camborthids | alluvial fan | loamy alluvium | A1-B2-Ck | 91 |
| Philder | Ustochreptic Paleorthids | alluvial fans | fan alluvium/eolian deposits | A1-B1k-B2k-C1k-K1-C3k | 30 |
| Reakor | Typic Calciorthids | upland slopes | limestone alluvium and colluvium | A1-B2k-B3k-Ck | 71 |
| Reeves | Typic Gypsiorthids | distal fan/basin floor | calcareous and gypsiferous alluvium | A1-B21-B22k-C1k-C2yk-C3yk | 51 |
| Simona | Typic Paleorthids | alluvial fans | loamy fan alluvium | Ak-Bk-K21-K22-K23-K3-Ck | 20 |
| Tencee | Typic Paleorthids | proximal alluvial fan | gravelly calcareous alluvium | A1-C1k-K1-C3k | 10 |
| Terino | Petrocalcic Ustollic Paleargids | older alluvial fan | gravelly alluvium | A1-B21t-B22ty-K1-K21-K22-K31-K32-Ck | 38 |
| Turney | Typic Calciorthids | basin floor | loamy distal fan/bajada | A11-A12-B2-C1k-C2 | 86 |
| Upton | Typic Paleorthids | alluvial fan | gravelly alluvium | A1-B21k-B22k-K1-K2-K3-Ck | 20 |
| Wink | Typic Calciorthids | dunes and sand sheets on fans and basin floor | calcareous eolian sediment | A11-A12-B2-C1k-C2k-C3 | 46 |

Table 2 (Concluded).

| SOIL ORDER Series Name | Subgroup | Typical Landscape Context | Parent Material | Typical Profile | Depth to Subsoil (cm) |
|---------------------------|-------------------------------|--|--|------------------------------|-----------------------------|
| MOLLISOLS | | | | | |
| Aladdin | Torriorthentic Haplustolls | fan and fan channel alluvium | mixed Holocene alluvium | A11-A12-A13-A14-A15-AC-C1-C2 | 117 |
| Cale | Aridic Argiustolls | basin floor, upland depressions | fine-medium sediment weathered from limestone | A1-B1-B21t-B22t-B3k-C | 114 |
| Deama | Lithic Calciustolls | upland slopes | limestone scree, colluvium, and regolith | A1-C1k-C2k-R | 10 |
| Ector | Lithic Calciustolls | upland slopes | limestone scree, colluvium, and regolith | A1-Ck-R | 23 |
| Espey | Petrocalcic Calciustolls | alluvial fans | mixed fan alluvium | A1-B2-C1k-K1-C3k | 28 |
| Holloman Var. | Typic Haplustolls | upland slopes | gypsiferous colluvium, residuum, and eolian deposits | A1-C1y-IIC2 | 30 |
| Kerrick | Petrocalcic Calciustolls | basin floor and distal bajada | mixed alluvium | A1-B2-B3k-K | 64 |
| Pena | Aridic Calciustolls | basin floor, distal bajada | mixed alluvium | A1-ACK-Ck | 36 |
| Reeves Var. | Aridic Calciustolls | basin floor | gypsiferous alluvium and playa sediments | A1-B21-B22y-C1y-C2y | 41 |
| Shanta | Cumulic Haplustolls | basin floor | cumulic mixed alluvium | A1-C1-C2 | 33 |
| ENTISOLS | | | | | |
| Anapra | Typic Torrifluvents | alluvial floodplains | recent, stratified loamy alluvium | A1-C1-C2 | 41 |
| Bluepoint | Typic Torripsamments | coppice dunes | eolian sands | A1-C1-C2-C3 | 20 |
| Brazito | Typic Torripsamments | alluvial floodplains | recent sandy alluvium | A1-C | 25 |
| Canutio | Typic Torriorthents | recent alluvial fans and fan-channels | recent gravelly alluvium | A1-C | 28 |
| Gila | Typic Torrifluvents | alluvial floodplains | recent, stratified loamy alluvium | A1-C1-C2-C3-C4 etc. | 38 |
| Glendale | Typic Torrifluvents | alluvial floodplains | recent, stratified loamy alluvium | A1-C1-C2 | 43 |
| Harkney | Typic Torrifluvents | alluvial floodplains | recent, stratified loamy alluvium | A1-C1-C2-C3-C4 etc. | 30 |
| Holloman | Typic Torriorthents | basin floor | gypsiferous eolian and playa sediment | A1-C1y-C2y-C3y | 8 |
| Lozier | Lithic Calciorthids | upland slopes, benches, and crests | limestone bedrock and colluvium | A11-A12-Ck-R | 18 |
| Pintura | Typic Torripsamments | coppice dunes | eolian sands | A1-C1-C2 | 30 |
| Reyab | Ustic Torriorthents | alluvial fans | limestone alluvium | A1-B21-B22-C | 64 |
| Saneli | Vertic Torrifluvents | alluvial floodplains | recent, stratified silty alluvium | A1-C1-C2-C3-C4 etc. | 30 |
| Tigua | Vertic Torrifluvents | alluvial floodplains | recent, stratified silty alluvium | A1-C1-C2 | 25 |

After Jaco 1971; Derr 1981; Gile et al. 1981. Horizon designations are updated to reflect current nomenclature.

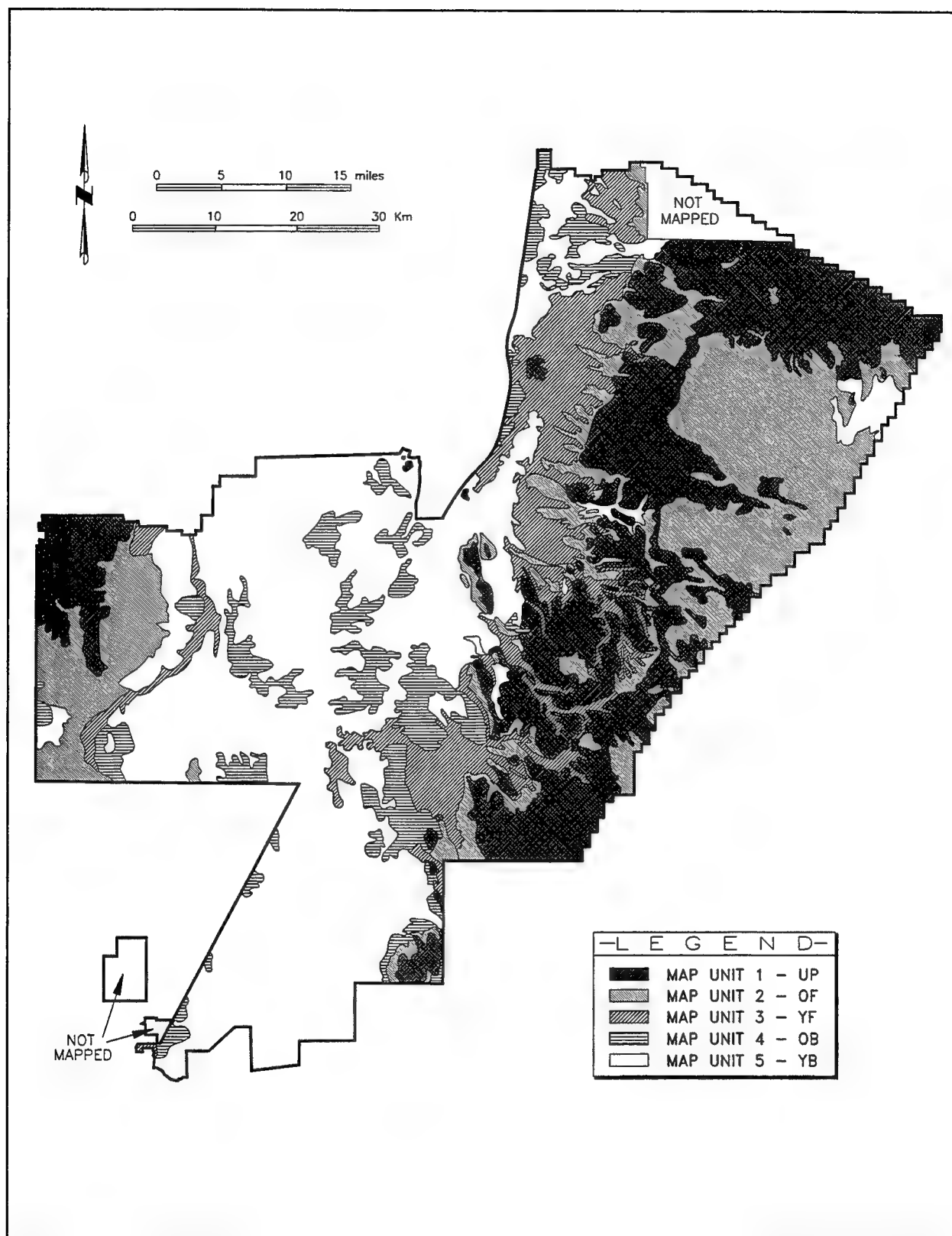


Figure 4 Simplified Map of Soil Distribution on Fort Bliss, Prepared from Fort Bliss GRASS Map of Soil Conservation Service Data (see text for description of mapping units).

Hueco Mountains, Otero Mesa, and the Sacramento Mountains; and the Pinaleno-Nolem association, Terino-Casito association, Simona-Harrisburg association, and Nickel-Upton association on the eastern flanks of the Organ and Franklin mountains. Most of these soils are Aridisols.

Map Unit 3 encompasses soil associations typical of younger, lower alluvial fans, bajada alluvium, and basin margin alluvium. Calcic horizons are common, but very strongly developed soils are typically buried or of relatively minor extent. Eolian deposits and soils of a variety of ages occur locally. Dominant soil associations in Map Unit 3 include the Mimbres-Tome complex on the eastern side of the bolson and the Aladdin-Coxwell Association and Mimbres-Tome complex on the western side of the bolson. Most of these soils are Entisols or Aridisols.

Map Unit 4 encompasses soil associations typical of older basin floor and distal bajada deposits in the bolsons. Calcic, cambic, and argillic horizons are common. Recent dunes cover portions of the area, and other weakly developed soils may occur locally. Dominant soil associations in Map Unit 4 include the Pintura-Tome-Doña Ana complex, 0 to 5% slopes, Doña Ana-Berino association, gently sloping, Onite-Pajarito association, Wink association level (eroded), and the Turney-Berino-Doña Ana complex. Most of these soils are Aridisols, although Entisols may occur locally on relatively recent sediments.

Map Unit 5 encompasses soil associations typical of the distal bajada and basin floor that are partially or totally mantled with more recent eolian and alluvial deposits. Older basin soils are frequently also a significant presence, but are so intimately associated that separate mapping is impossible. Most coppice dune fields are associated with this mapping unit. Dominant soil associations in Map Unit 5 include the Bluepoint-Onite-Wink association, nearly level; Tome silt loam, 0% to 5% slopes; the Berino-Pintura complex; and the Pintura-Doña Ana-Hueco-Wink complex. Most of these soils are Entisols or Aridisols.

2.4 FLORA AND FAUNA

2.4.1 Modern Vegetation

Like the soils, vegetation on Fort Bliss is strongly conditioned by landscape position, elevation, and parent materials (Satterwhite and Ehlen 1980; Kenmotsu 1977). The vegetation on the fort is transitional between the Chihuahuan Desert and the Southern Great Plains (Shreve 1942). Although some grasses more typical of the southern short-grass prairie occur, the plants in the bolson are for the most part typical of the Chihuahuan Desert, and consist primarily of grasses, forbs, and shrubs adapted to xeric conditions. The higher elevations, in contrast, are dominated by grasses and trees indicative of greater moisture. There is considerable evidence that grassland was considerably more widespread on the bolson floor prior to historic disturbance, which allowed the xeric species to invade and dominate. Principal plants occurring on the installation are listed in Table 3.

Satterwhite and Ehlen (1980) identified 22 distinct plant communities on Fort Bliss, while Budd et al. (1979), working at a finer scale, identified 164 different, mappable plant associations (which are composed of variable percentages of ten basic taxa: grasses, sand sage, creosote bush, tarbush, mesquite, broom dalea, fourwing saltbush, soaptree yucca, littleleaf sumac, and whitethorn). These communities comprise four basic physiognomic groups: grassland, which comprises 37% of the area of the fort; shrubland, which comprises 58%; forestland, which comprises 2%; and "other," which includes bare ground, water bodies, and built-up areas, and comprises another 2% of the total area (Satterwhite and Ehlen 1980).

Table 3 Flora of the Fort Bliss Region.

| Family | Taxon | Common Name | Ethnobotanical Uses |
|------------------------------|---------------------------------|-------------------------------|--|
| Polypodiaceae (true ferns) | <i>Cheilanthes wrightii</i> | Wright lipfern | |
| Pinaceae (pine family) | <i>Juniperus monosperma</i> | oneseed juniper; cedar | variety of medicinal, food, and material uses |
| | <i>Pinus edulis</i> | piñon pine | food source (nuts); variety of sealing and adhering uses (sap); construction material (wood) |
| Ephedraceae (ephedra family) | <i>Ephedra aspera</i> | popotillo; mormon tea | |
| | <i>Ephedra trifurca</i> | long-leaf ephedra; mormon tea | medicinal (for diarrhea); beverage |
| Graminaea (grasses) | <i>Andropogon barbinodis</i> | | |
| | <i>Andropogon saccharoides</i> | silver beardgrass | |
| | <i>Aristida adscensionis</i> | six weeks three-awn | |
| | <i>Aristida arizonica</i> | Arizona three-awn | |
| | <i>Aristida divericata</i> | Poverty three-awn | |
| | <i>Aristida longiseta</i> | red three-awn | |
| | <i>Aristida pansa</i> | Wooten three-awn | |
| | <i>Aristida parishii</i> | | |
| | <i>Aristida purpuraascens</i> | arrow feather | |
| | <i>Bouteloua breviseta</i> | six weeks grama | minor source of seed grain |
| | <i>Bouteloua barbata</i> | | minor source of seed grain |
| | <i>Bouteloua curtipendula</i> | side oats grama | minor source of seed grain; used for brooms |
| | <i>Bouteloua eriopoda</i> | black grama | minor source of seed grain; used for hair brushes |
| | <i>Bouteloua gracilis</i> | blue grama | minor source of seed grain |
| | <i>Bouteloua hirsuta</i> | hairy grama | minor source of seed grain |
| | <i>Bouteloua uniflora</i> | | minor source of seed grain |
| | <i>Cenchrus pauciflorus</i> | field sandbur | |
| | <i>Chloris virgata</i> | feather fingergrass | |
| | <i>Echinocloa crusgalli</i> | barnyard grass | |
| | <i>Enneopogon desvauxii</i> | spiked pappusgrass | |
| | <i>Eragrostis intermedia</i> | plains lovegrass | seed grain |
| | <i>Hilaria belangeri</i> | curly mesquite | |
| | <i>Hilaria mutica</i> | tobosa grass | used in basketry, on prayer sticks |
| | <i>Leptochloa dubia</i> | green sprangletop | |
| | <i>Lycurus phleoides</i> | wolftail | |
| | <i>Muhlenbergia arenacea</i> | | seed grain |
| | <i>Muhlenbergia arenicola</i> | | seed grain |
| | <i>Muhlenbergia emersleyi</i> | bullgrass | seed grain |
| | <i>Muhlenbergia pauciflora</i> | New Mexican muhly | seed grain |
| | <i>Muhlenbergia porteri</i> | bush muhly | seed grain |
| | <i>Muhlenbergia pungens</i> | | seed grain |
| | <i>Muhlenbergia reventchoni</i> | | seed grain |
| | <i>Muhlenbergia rigida</i> | purple muhly | seed grain |
| | <i>Muhlenbergia setifolia</i> | | seed grain |
| | <i>Muhlenbergia torreyi</i> | ring grass | seed grain |
| | <i>Muhlenbergia xerophila</i> | | seed grain |
| | <i>Panicum obtusum</i> | vine-mesquite | food source (seeds) |

| Table 3 (Continued). | | | |
|-----------------------------------|---|------------------------------|--|
| Family | Taxon | Common Name | Ethnobotanical Uses |
| | <i>Panicum pampinosum</i> | | |
| | <i>Scleropogon brevifolius</i> | burro grass | |
| | <i>Setaria macrostachya</i> | plains bristlegrass | seed grain |
| | <i>Sporobolus asper</i> | | |
| | <i>Sporobolus contractus</i> | spike dropseed | |
| | <i>Sporobolus cryptandrus</i> | sand dropseed | seed grain |
| | <i>Sporobolus flexuosus</i> | mesa dropseed | |
| | <i>Sporobolus giganteus</i> | giant dropseed | |
| | <i>Sporobolus wrightii</i> | sacaton | |
| | <i>Stipa pringlei</i> | pringle needlegrass | |
| | <i>Trichachne californica</i> | cottontop | |
| | <i>Trichachne hitchcockii</i> | | |
| | <i>Tridens elongatus</i> | rough tridens | |
| | <i>Tridens muticus</i> | slim tridens | |
| | <i>Tridens pulchellus</i> | | |
| Liliaceae (lily family) | <i>Dasyilirion wheeleri</i> | Wheeler sotol | Food source; fiber source; stalk can be used as spear shaft |
| | <i>Nolina spp.</i> | | fiber source (leaves); source of meal (seeds) |
| | <i>Yucca baccata</i> | datil; banana yucca | food source (fruit); fiber (leaves); soap (roots) |
| | <i>Yucca elata</i> | soaptree yucca | food source (crowns, young leaves and flower buds, fruit); soap (roots); fiber (leaves) |
| | <i>Yucca torreyi</i> | Spanish dagger; Torrey yucca | fiber (leaves) |
| Amaryllidaceae (amaryllis family) | <i>Agave lecheguilla</i> | lecheguilla | leaves yield fiber; roots can yield soap substitute |
| | <i>Agave parryi</i> | mescal; Parry agave | food source |
| Salicaceae (willow family) | <i>Populus sp.</i> | cottonwood; poplar | construction material; wide variety of ceremonial uses (wood) |
| | <i>Salix gooddingii</i> | Southwestern black willow | construction material |
| Fagaceae (beech family) | <i>Quercus undulata</i> | wavy leaf oak | food source (acorns), wood source |
| Ulmaceae (elm family) | <i>Celtis reticulata</i> | netleaf hackberry | fruit is a food source |
| | <i>Ulmus spp.</i> | elm | |
| Chenopoaceae (goosefoot family) | <i>Atriplex canescens</i> | fourwing saltbush | food seasoning (leaves); medicinal (salve made from roots, blossoms); purple dye from inner bark |
| | <i>Eurotia lanata</i> | common winterfat | food source (roots); medicinal (roots, leaves) |
| | <i>Salsola kali</i> | Russian thistle; tumbleweed | |
| Brassicaceae (mustard family) | <i>Dithyrea wislizenii</i> | Wislizenus spectaclepod | variety of medicinal uses |
| | <i>Lepidium lasiocarpum</i> | hairypod spectaclepod | food (condiment) |
| | <i>Lepidium montanum</i> var. <i>alyssoides</i> | mountain pepperweed | food (condiment) |

| Table 3 (Continued). | | | |
|---------------------------------------|--|---------------------------------|---|
| Family | Taxon | Common Name | Ethnobotanical Uses |
| | <i>Lepidium montanum</i> var. <i>angustifolium</i> | fleshy pepperweed | food (condiment) |
| Rosacea (rose family) | <i>Cercocarpus montanus</i> | shaggy mountain mahogany | medicinal (laxative); food (beverage from outer bark); |
| | var. <i>paucidentatus</i> | | branches used for arrows; leaves used to wash hair |
| | <i>Fallugia paradoxa</i> | Apache plume | |
| Leguminosaea (legumes) | <i>Acacia constricta</i> | mescat acacia; whitethorn | legume used as food source |
| | <i>Caesalpinia jamesii</i> | bird-of-paradise | |
| | <i>Cassia lindheimeriana</i> | Lindheimer senna | |
| | <i>Dalea formosa</i> | feather dalea | |
| | <i>Dalea lanata</i> | wooly dalea | |
| | <i>Dalea scoparia</i> | broom dalea | |
| | <i>Hoffmanseggia glauca</i> | rush pea | |
| | <i>Parkinsonia aceleata</i> | | |
| | <i>Prosopis glandulosa</i> | western honey mesquite | food source (seeds, pods) |
| Krameriaceae (ratany family) | <i>Krameria ramosissima</i> | calderona | |
| | <i>Krameria glandulosa</i> | range ratany | |
| Zygophyllaceae (caltrop family) | <i>Larrea tridentata</i> | creosote; greasewood | medicinal (emetic) |
| Anacardiaceae (sumac family) | <i>Rhus aromatica</i> var. <i>pilosissima</i> | skunkbush; fragrant sumac | food source (fruit) |
| | <i>Rhus microphylla</i> | littleleaf sumac | |
| Rhamnaceae (buckthorn family) | <i>Ceanothus greggi</i> | desert ceanothus | |
| | <i>Condalia ericoides</i> | javelina bush | |
| | <i>Condalia mexicana</i> | | |
| | <i>Condalia spathulata</i> | knifelead condalia | |
| Malvaceae (mallow family) | <i>Hibiscus denudatus</i> | paleface rosemallow | |
| | <i>Spharalcea</i> sp. | | |
| Fouquieriaceae (ocotillo family) | <i>Fouquieria splendens</i> | ocotillo | stems bundled and used in construction |
| Koeberliniaceae (allthorn family) | <i>Koeberlinia spinosa</i> | allthorn | |
| Cactaceae (cacti) | <i>Opuntia engelmannii</i> | Engelman prickly pear | food source (tunas, pads) |
| | <i>Opuntia imbricata</i> var. <i>imbricata</i> | cane cholla; tree cholla | food source (tunas) |
| | <i>Opuntia leptocaulis</i> var. <i>leptocaulis</i> | pencil cholla; Christmas cactus | food source (tunas) |
| | <i>Opuntia</i> spp. | | |
| Tamaraceae (tamarisk family) | <i>Tamarisk ramosissima</i> | salt cedar | |
| Convolvulaceae (morning glory family) | <i>Ipomoea</i> sp. | morning glory | |
| Verbenaceae (verbain family) | <i>Aloysia wrightii</i> | Wright aloysia | |
| | <i>Nicotiana trigonophylla</i> | desert tobacco | medicinal/ceremonial (smoked) |
| | <i>Solanum elaeagnifolium</i> | silverleaf nightshade | medicinal (analgesic) |
| Scrophulariaceae (figwort family) | <i>Castilleja</i> sp. | indian paintbrush | medicinal (stem menstrual flow, contraceptive) |
| Bignoniaceae (catalpa family) | <i>Chilopsis linearis</i> var. <i>linearis</i> | desert willow | |
| Curcubitaceae (gourd family) | <i>Curcubita foetidissima</i> | buffalo gourd | food source (seeds); utensil/container/rattle; roots used as laxative |

Table 3 (Concluded).

| Family | Taxon | Common Name | Ethnobotanical Uses |
|-------------------------------|-------------------------------------|-----------------------|---|
| Asteraceae (sunflower family) | <i>Artemisia filifolia</i> | sand sage | variety of medicinal uses (principally salves) |
| | <i>Baccharis glutinosa</i> | seepwillow baccharis | |
| | <i>Baileya multiradiata</i> | desert baileya | Often used as a binder in adobe |
| | <i>Chrysothamnus nauseosus</i> | rubber rabbitbrush | stems yield basket fibers; flowers can yield yellow dye |
| | <i>Dyssodia acerosa</i> | prickleleaf dogweed | |
| | <i>Flourensia cernua</i> | tarbush; blackbrush | |
| | <i>Gaillardia pinnatifida</i> | slender gaillardia | medicinal (diuretic) |
| | <i>Parthenum incanum</i> | mariola parthenium | |
| | <i>Psilostrophe tagetina</i> | wooly paperflower | yellow dye source |
| | <i>Thelesperma longipes</i> | longstalk greenthread | |
| | <i>Viguiera stenoloba</i> | skeleton goldeneye | |
| | <i>Xanthocephalum microcephalum</i> | threadleaf snakeweed | |
| | <i>Xanthocephalum sarothrae</i> | broom snakeweed | medicinal (salve) |

Adapted from Satterwhite and Ehlen 1980 and Kenmotsu 1977.

As is apparent in the preceding statistics, grasslands and shrublands make up the overwhelming majority of the fort. In general, each of the principal landform elements on Fort Bliss (e.g., bolson floor, alluvial fans, mountains, and Otero Mesa) supports a variety of distinct plant communities. The general distribution of these communities is illustrated in Figure 5. Much more detailed mapping of the vegetation on portions of Fort Bliss is provided by Satterwhite and Ehlen (1980) and Budd et al. (1979).

The Sand Dune-Mesquite zone (Map Unit 1) is typical of the bolson floor. Satterwhite and Ehlen (1980) identify a number of plant communities within this zone. The most prevalent is a mesquite, broom snakeweed, fourwing saltbush, grass community, which is typical of the areas occupied by coppice dunes.

The larger dune areas typically vegetated by sand sage, grasses (especially dropseed grasses), some mesquite, broom snakeweed, and fourwing saltbush. Closed depressions, older playas, and level basin surfaces are typified by dropseed grasses and sand sage, with some creosote, tarbush, and soaptree yucca. Active playas are typified by

a grassy association dominated by tobosa grass and bush muhly.

The Alluvial Fan-Creosote bush zone (Map Unit 2) is typical of the broad, gently sloping bajada surfaces on the margins of the basin. As the name implies, this area is dominated by creosote, and contrasts markedly with the plant associations in the basin. On the higher, gravelly fan surfaces, creosote and occasional creosote-grassland communities are dominant, while yucca, ocotillo, and cacti are also present in very limited numbers. The lower, finer-grained fans support somewhat more diverse communities; while creosote is still frequently the dominant taxon, tarbush also dominates in places and occurs as an important secondary species in others. Other taxa such as mesquite, tarbush, broom snakeweed, tobosa grass, and burro grass also occur. In areas where the fans are covered by eolian sands, creosote competes with mesquite, fourwing saltbush, grasses, sand sage, and other species typical of the basin; with increasing sand depth and sediment influx, the creosote assemblage is replaced by a mesquite-four-wing saltbush assemblage (Satterwhite and Ehlen 1980; Kenmotsu 1977).

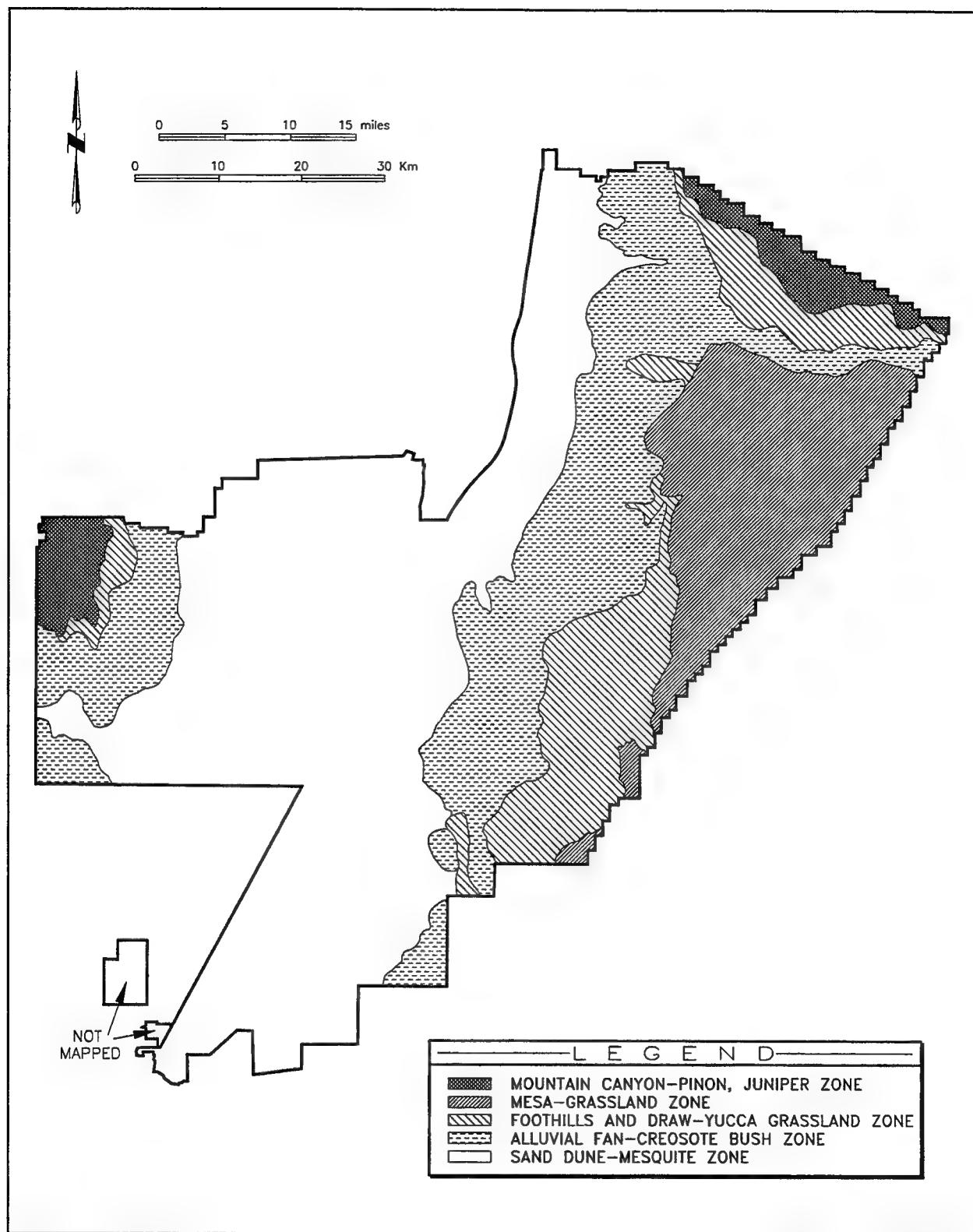


Figure 5 Map of the Distribution of Major Vegetation Communities on Fort Bliss. Adapted from Satterwhite and Ehlen 1980 (see text for description of map units).

The Foothills & Draws-Yucca Grassland zone (Map Unit 3) occurs on the Hueco Mountains, high fans, and dissected terrain below the Otero Mesa escarpment. It represents a transition from the creosote-dominated alluvial fans and the grassy uplands on Otero Mesa. Creosote is dominant on the higher parts of the terrain, but the assemblage is relatively diverse and may include ocotillo, Spanish dagger, allthorn, Mormon tea, cholla, prickly pear, and a variety of xeric grasses. Relatively lush grasses, including muhlys, dropseeds, three-awns, gramas, and tobosa are typical of the lower parts of the dissected landscape, where they coexist with the same shrub species typical of the higher parts of the local landscape (Kenmotsu 1977; U.S. Army Corps of Engineers 1993).

The Mesa-Grassland zone (Map Unit 4) is typical of Otero Mesa. Grasses, dominated by various species of grama, muhly, and dropseed, make up the principal association. Shrubs occur individually and in isolated stands on the mesa, but are primarily concentrated along arroyo drainages and the mesa margin. Common taxa include creosote, mariola parthenium, fourwing saltbush, soaptree yucca, cane cholla, javelina bush, and broom snakeweed, while little-leaf sumac and skeleton goldeneye are common on arroyo margins, and desert willow and apache plume common in arroyo channels (Kenmotsu 1977; Satterwhite and Ehlen 1980).

The Mountain Canyon-Piñon Juniper zone (Map Unit 5) is restricted to the Organ Mountains and southern Sacramento Mountains, generally above 6,000 ft amsl. Here, the typical Yucca Grassland taxa (Map Unit 3) are joined by scattered piñon pine and juniper. Localized stands of ponderosa pine, Douglas fir, and quaking aspen are also present in relatively sheltered locations in the mountains (Jim Bowman, personal communication, 1996). Secondary shrubs include wavy leaf oak, sotol, mountain mahogany, agave, and sumac. This map unit is also characterized by patchy, but occasionally relatively lush stands of grass, including blue and side-oats grama, plains

bristlegrass, and bush muhly (Piggott 1977; U.S. Army Corps of Engineers 1993).

Many of the species occurring on Fort Bliss were potentially exploited by the prehistoric people. Plants could be used for food, medicinal purposes, or materials (e.g., fibers, glue, building materials). Kenmotsu (1977) includes a list of 116 taxa occurring on McGregor Range that were potentially used by prehistoric people in the area. The potential uses of the most common plants currently occurring on the reservation are listed in Table 3.

2.4.2 Modern Fauna

Animals in the region of Fort Bliss are typical of the northern Chihuahuan Desert (Cully 1973a; 1973b). Table 4 presents a partial list of vertebrate taxa noted in the vicinity of Fort Bliss. In general, species diversity is highest in the mountains and lowest in the bolson (U.S. Army COE 1993). Larger animals are generally restricted to the higher elevations where cover and forage is more abundant. Fauna in the bolson is dominated by birds, rodents (especially rabbits), and lizards. However, a few larger game animals (e.g., pronghorn) are occasionally found in the bolson, as well as in the mountains and on Otero Mesa. Although other large game animals (e.g., bison) may have been present at different times in the past, archeological investigations suggest that small game, and particularly rabbits, were much more important food sources during most of the prehistoric period.

Macroscopic invertebrate animals are also present in the vicinity in a number of diverse forms. Insects (e.g., flies, ants, beetles, and termites), chilopods (e.g., centipedes and millipede) and arachnids (spiders, ticks, and scorpions) are probably the most common types of macroinvertebrates, but worms and snails also may be present, particular at altitude. Ants and termites are common in the bolson, and are probably a very important factor in the pervasive bioturbation apparent in the eolian deposits of the bolson floor.

Table 4 Partial List of Faunal Taxa Occurring in the Vicinity of Fort Bliss.

| | Order | Taxon | Common Name |
|---------|--|---|--------------------------|
| Mammals | Chiroptera (bats) | <i>Tadarida brasiliensis</i> | Mexican freetail bat |
| | | <i>Myotis californicus</i> | California myotis |
| | | <i>Lasiurus cinereus</i> | hoary bat |
| | | <i>Antrozous pallidus</i> | pallid bat |
| | | <i>Plecotus townsendii</i> var. <i>pallidus</i> | Townsend's big-eared bat |
| | Rodentia (rodents) | <i>Tamiasciurus hudsonicus</i> | red squirrel |
| | | <i>Eutamias cinereicollis</i> | greyneck chipmunk |
| | | <i>Spermophilus variegatus</i> | rock squirrel |
| | | <i>Spermophilus spilosoma</i> | spotted ground squirrel |
| | | <i>Dipodomys merriami</i> | kangaroo rat |
| | | <i>Perognathus penicillatus</i> | desert pocket mouse |
| | | <i>Perognathus flavescens</i> | plains pocket mouse |
| | | <i>Thomomys bottae</i> | valley pocket gopher |
| | | <i>Peromyscus eremicus</i> | cactus mouse |
| | | <i>Peromyscus difficilis</i> | rock mouse |
| | | <i>Peromyscus boyleyi</i> | brush mouse |
| | | <i>Peromyscus maniculatus</i> | deer mouse |
| | | <i>Reithrodontomys</i> sp. | western harvest mouse |
| | | <i>Neotoma albigula</i> | whitethroated woodrat |
| | | <i>Neotoma mexicana</i> | Mexican woodrat |
| | | <i>Microtus longicaudus</i> | long-tailed vole |
| | | <i>Microtus montanus</i> | mountain vole |
| | | <i>Erethizon dorsatum</i> | porcupine |
| | | <i>Lepus californicus</i> | blacktail jackrabbit |
| | Lagomorpha (hares, rabbits, and pikas) | <i>Sylvilagus auduboni</i> | desert cottontail |
| | Carnivora (carnivores) | <i>Canis latrans</i> | coyote |
| | | <i>Urocyon cinereoargenteus</i> | grey fox |
| | | <i>Bassariscus astutus</i> | ringtail cat |
| | | <i>Procyon lotor</i> | raccoon |
| | | <i>Mephitis mephitis</i> | striped skunk |
| | | <i>Taxidea taxus</i> | badger |
| | | <i>Felis concolor</i> | mountain lion |
| | | <i>Lynx rufus</i> | bobcat |
| | | <i>Ursus americanus</i> | black bear |
| | Artiodactyla (even-toed ungulates) | <i>Odocoileus virginianus</i> | white-tailed deer |
| | | <i>Odocoileus hemionus</i> | mule deer |
| | | <i>Antilocapra americana</i> | pronghorn |
| | | <i>Dicotyles tajacu</i> | javelina |
| | | <i>Cervus canadensis</i> | elk |
| Birds | | <i>Cathartes aura</i> | turkey vulture |
| | | <i>Accipiter striatus</i> | sharp-skinned hawk |

Table 4 (Continued).

| Order | Taxon | Common Name |
|---------------|----------------------------------|---------------------------|
| Birds (cont.) | <i>Accipiter cooperii</i> | Cooper's hawk |
| | <i>Buteo jamaicensis</i> | red-tailed hawk |
| | <i>Aquila chrysaetos</i> | golden eagle |
| | <i>Falco sparverius</i> | sparrow hawk |
| | <i>Callipepla squamata</i> | scaled quail |
| | <i>Lophortyx gambelii</i> | Gambel's quail |
| | <i>Meleagris gallopavo</i> | wild turkey |
| | <i>Columba fasciata</i> | band-tailed pigeon |
| | <i>Zenaidura macroura</i> | mourning dove |
| | <i>Geococcyx californianus</i> | roadrunner |
| | <i>Bubo virginianus</i> | great horned owl |
| | <i>Glaucidium gnoma</i> | pygmy owl |
| | <i>Phalaenoptilus nuttallii</i> | poor-will |
| | <i>Chordeiles minor</i> | common nighthawk |
| | <i>Chordeiles acutipennis</i> | lesser nighthawk |
| | <i>Aeronautes saxatalis</i> | white-throated swift |
| | <i>Archilochus alexandri</i> | black-chinned hummingbird |
| | <i>Selasphorus platycercus</i> | broad-tailed hummingbird |
| | <i>Colaptes cafer</i> | red-shafted flicker |
| | <i>Melanerpes formicivorus</i> | acorn woodpecker |
| | <i>Sphyrapicus varius</i> | yellow-bellied sapsucker |
| | <i>Dendrocopos villosus</i> | hairy woodpecker |
| | <i>Dendrocopos scalaris</i> | ladder-backed woodpecker |
| | <i>Tyrannus verticalis</i> | western kingbird |
| | <i>Myiarchus cinerascens</i> | ash-throated flycatcher |
| | <i>Sayornis nigricans</i> | black phoebe |
| | <i>Sayornis saya</i> | Say's phoebe |
| | <i>Empidonax difficilis</i> | western flycatcher |
| | <i>Contopus sordidulus</i> | western wood peewee |
| | <i>Tachycineta thalassina</i> | violet-green swallow |
| | <i>Petrochelidon pyrrhonota</i> | cliff swallow |
| | <i>Progne subis</i> | purple martin |
| | <i>Cyanocitta stelleri</i> | stellar's jay |
| | <i>Aphelocoma coerulescens</i> | scrub jay |
| | <i>Corvus corax</i> | common raven |
| | <i>Gymnorhinus cyanocephalus</i> | pinon jay |
| | <i>Parus gambeli</i> | mountain chickadee |
| | <i>Parus inornatus</i> | plain titmouse |
| | <i>Auriparus flaviceps</i> | verdin |
| | <i>Psaltiriparus minimus</i> | common bushtit |
| | <i>Psaltiriparus melanotis</i> | black-eared bushtit |
| | <i>Sitta carolinensis</i> | white-breasted nuthatch |
| | <i>Troglodytes aedon</i> | house wren |

Table 4 (Continued).

| Order | | Taxon | Common Name |
|---------------|------------------|-----------------------------------|-----------------------------|
| Birds (cont.) | | <i>Thyromanes bewickii</i> | Bewick's wren |
| | | <i>Catherpes mexicanus</i> | canon wren |
| | | <i>Salpinctes obsoletus</i> | rock wren |
| | | <i>Mimus polyglottos</i> | mockingbird |
| | | <i>Toxostoma dorsale</i> | Crissal thrasher |
| | | <i>Turdus migratorius</i> | robin |
| | | <i>Hylocichla guttata</i> | hermit thrush |
| | | <i>Sialia mexicana</i> | western bluebird |
| | | <i>Poliophtila caerulea</i> | blue-gray gnatcatcher |
| | | <i>Lanius ludovicianus</i> | loggerhead shrike |
| | | <i>Vireo solarius</i> | solitary vireo |
| | | <i>Virio gilvus</i> | warbling vireo |
| | | <i>Vermivora virginiana</i> | Virginia's warbler |
| | | <i>Dendroica auduboni</i> | Audobon's warbler |
| | | <i>Dendroica nigrescens</i> | black-throated gray warbler |
| | | <i>Dendroica graciae</i> | Grace's warbler |
| | | <i>Oporornis tolmiei</i> | MacGillivray's warbler |
| | | <i>Geothlypis trichas</i> | yellowthroat |
| | | <i>Icteria virens</i> | yellow-breasted chat |
| | | <i>Cardellina rubrifrons</i> | red-faced warbler |
| | | <i>Passer domesticus</i> | house sparrow |
| | | <i>Icterus parisorum</i> | Scott's oriole |
| | | <i>Molothrus ater</i> | brown-headed cowbird |
| | | <i>Piranga ludoviciana</i> | western tanager |
| | | <i>Pheucticus melanocapthalus</i> | black-headed grosbeak |
| | | <i>Giuraca caerulea</i> | blue grosbeak |
| | | <i>Passerina cyanea</i> | indigo bunting |
| | | <i>Hesperiphona vespertina</i> | evening grosbeak |
| | | <i>Carpodacus mexicanus</i> | house finch |
| | | <i>Spinus pinus</i> | pine siskin |
| | | <i>Spinus tristis</i> | American goldfinch |
| | | <i>Spinus psaltria</i> | lesser goldfinch |
| | | <i>Chlorura chlorura</i> | green-tailed towhee |
| | | <i>Pipilo fuscus</i> | brown towhee |
| | | <i>Aimophila ruficeps</i> | rufous-crowned sparrow |
| | | <i>Amphispiza bilineata</i> | black-throated sparrow |
| | | <i>Junco caniceps</i> | gray-headed junco |
| | | <i>Spizella passerina</i> | chipping sparrow |
| | | <i>Spizella atrogularis</i> | black-chinned sparrow |
| Reptiles | Sauria (lizards) | <i>Cophosaurus texanus</i> | greater earless lizard |
| | | <i>Phrynosoma modestum</i> | round-tail horned lizard |
| | | <i>Cnemidophorus spp.</i> | whiptail lizards |
| | | <i>Sceloporus spp.</i> | spiny lizards |

| Table 4 (Concluded). | | | |
|-------------------------------------|--|---------------------------------|--|
| Order | Taxon | Common Name | |
| Reptiles (cont.) Serpentes (snakes) | <i>Masticophis taeniatus</i> vars. | whipsnakes | |
| | <i>Masticophis flagellum</i> var. <i>testaceus</i> | coachwhips | |
| | <i>Elaphe</i> spp. | ratsnakes | |
| | <i>Croatalus atrox</i> | western diamondback rattlesnake | |
| | <i>Croatalus molossus</i> | blacktail rattlesnake | |
| | <i>Croatalus viridis</i> vars. | western rattlesnakes | |

After Cully 1973a, 1973b, and U.S. Army COE 1993.

2.5 BEDROCK GEOLOGY

2.5.1 Stratigraphy

The Fort Bliss region is dominated by rock and sediments of two broad ages: those predating the Laramide Orogeny, and those penecontemporaneous with or postdating this tectonic episode. The block-faulted mountains expose sedimentary and metasedimentary rocks, primarily of Precambrian to Permian age, that were strongly fractured and tilted by extensional tectonics during the (Tertiary) Laramide Orogeny. These exposed rocks represent the pre-Laramide sequence. Roughly coincident with this episode of mountain building, a number of intrusive plutons and extrusive volcanics were emplaced, including intrusive rocks forming the core of the Jarilla and Organ mountains. At the same time, sedimentary deposits began to accrete in the bolsons, eventually filling the structural basins with thousands of feet of sediments. Table 5 illustrates the generalized stratigraphic sequences in the bolsons and in the Franklin, Hueco, Organ, and Sacramento mountains.

The oldest exposed rocks in the region date to the latter Precambrian (Proterozoic), and include both intrusive igneous rocks and weakly to strongly metamorphosed igneous and sedimentary rocks (Barnes 1983; Seager et al. 1987; Denison and Hetherington 1969; Nelson 1940; Nelson and Haigh 1958; Kottowski 1975; Thomann and Hoffer 1985; 1989). The stratigraphically lowest rocks, termed the Castner Limestone (or Castner

Marble) and the Mundy Breccia, are exposed in the Franklin and (possibly) Sacramento mountains. The Castner Limestone Formation consists of metasedimentary limestone, dolomite, conglomerate, chert, rocks strongly altered by contact metamorphism (hornfels), and sills of intrusive igneous rock (diabase) (Hoffer 1976). The Mundy Breccia consists of black basalt boulders in a mudstone matrix. The youngest Precambrian metasedimentary rock is the Lanoria Quartzite Formation, which includes beds of sandstone, quartzite, siltstone, and shale. It too is described only from the Franklin Mountains, although an equivalent unit may occur in the so called DeBaca Terrain at the base of the Sacramento Mountains. The most recent Precambrian rocks consist of rhyolitic and granitic intrusives, including the Franklin Mountain Rhyolite and Red Bluff Granite, which are noted in the Franklin and Hueco mountains (Barnes 1983; Denison and Hetherington 1969).

Paleozoic rocks are widespread in the region, and occur in all of the block-faulted ranges (LeMone 1969a; 1969b; 1982; 1989; LeMone and Cornell 1988; Harbour 1972; Nelson and Haigh 1958; Kottowski 1975; Toomey and Babcock 1983; McAnulty 1967). The oldest formation noted in all of the ranges is the Bliss Sandstone, which dates from the upper Cambrian to lower Ordovician. It is roughly 250 ft thick and consists of thick bedded sandstone that forms a relatively steep face in outcrop. The Bliss Sandstone is overlain by sedimentary rocks of the lower Ordovician El Paso Group, including limestone,

Table 5 Generalized Stratigraphy of the Fort Bliss Region.

| | | | Franklin Mountains (Denison and Hetherington 1969; Barnes 1983; LeMone 1969; Lovejoy 1975) | Hueco Mtns (Nelson and Haigh 1958; Denison and Hetherington 1969; Barnes 1983) | Organ Mtns (Glover 1975; Seager 1981) | Sacramento Mountains (Pray 1961; Pigott 1977) | Tularosa and Hueco Bolsons (Strain 1966; Gustafson 1991; Seager et al. 1987) |
|--------------------|----------------------------|--|---|---|---|---|--|
| Cenozoic | Quaternary | Holocene | Post-Santa Fe fans, sheetwash, debris flows, paludal sediments, and eolianites | | | | |
| | | Pleistocene | Upper Santa Fe Group (Camp Rice Fm., Ft. Hancock Fm., Rincon Valley Fm., Hayner Ranch Fm.); post Santa Fe deposits | | | | |
| | Tertiary | Pliocene | Upper Santa Fe Group (Ft. Hancock Fm.) | | | | |
| | | Miocene | Lower Santa Fe Group | | | | |
| | | Oligocene | Various Intrusives | Various Intrusives | Cueva Rhyolite, Soledad Rhyolite, Organ Mountain Quartz Monzonite | Various Intrusives | Lower Santa Fe Group; various intrusives, lava flows, and tuffs (includes Jarilla Mtn. pluton) |
| | | Eocene | Various Intrusives | Various Intrusives | Oregon Andesite | Various Intrusives | |
| | | Paleocene | Love Ranch Fm. | | | | Love Ranch Fm. |
| Mesozoic | Cretaceous | Gulfian Series (undifferentiated limestone, marl, shale, and sandstone) | | | | | |
| | | Comanchean Series (undifferentiated limestone, marl, shale, and sandstone) | | | | | Washita rocks undivided, Finlay Limestone, Cox Sandstone, Bluff Mesa Fm., Campagrande Fm. |
| Paleozoic | Permian | | Hueco Limestone Group (Alacran Mtn. Fm., Cerro Alto Limestone, Hueco Canyon Fm) | Hueco Limestone (Alacran Mtn Fm., Cerro Alto Limestone, Hueco Canyon Fm., Powwow Conglomerate Member) | Hueco Limestone | San Andres Limestone, Yeso Fm. (San Yesidro Member and Meseta Blanca Member), Abo Sandstone, Pendejo Siltstone, Hueco Limestone | |
| | Pennsylvanian | | Magdalena Group (unnamed member, Bishops Cap Fm., Berino Fm., La Tuna Fm.) | Magdalena Limestone | Magdalena Group | Magdalena Group | |
| | Mississippian | | Helms Fm., Rancheria Fm., Las Cruces Fm | Helms Fm. | Rancheria Fm., Las Cruces Fm., Lake Valley Limestone, Caballero Fm. | Helms Fm., Rancheria Fm., Arcento Fm., Alamagordo-Andreito Fm., Caballero Fm. | |
| | Devonian | | Percha Shale, Canutillo Fm | Undifferentiated cherty limestone and shale | Percha Shale | Percha Shale, Onate Fm | |
| | Silurian | | Fusselman Dolomite | Fusselman Dolomite | Fusselman Dolomite | | |
| | Ordovician | | Montoya Dolomite (Cutter Member Aleman Member Upham Member Cable Canyon Sandstone Member) | Montoya Dolomite (Cutter Member, Aleman Member, Upham Member, Cable Canyon Sandstone Member) | Montoya Group | Montoya Dolomite (Valmont Dolomite, Aleman Member, Upham Member, Cable Canyon Member) | |
| | | | El Paso Group (Florida Mtns Fm., Scenic Drive Fm., McKelligan Canyon Fm., Jose Fm., Victoria Hills Fm., Cooks Fm., Sierrite Fm) | El Paso Group (Bat Cave Fm., Sierrite Limestone) | El Paso Group | El Paso Fm | |
| | Cambrian-Ordovician | | Bliss Sandstone | Bliss Sandstone | Bliss Sandstone | Bliss Sandstone | |
| Precambrian | Proterozoic | | Red Bluff Granite, Franklin Mountain Rhyolite, Lanoria Quartzite, Hazel Fm., Mundy Breccia, Castner Marble | Red Bluff Granite equiv. | DeBaca Terrane (quartzites, siltstones, shale cut with sills and dikes) | | |

dolomite, and sandstone rocks. The El Paso Group is up to 1,600 ft thick, and is subdivided into a variety of formations in the various ranges; like the Bliss Sandstone, it occurs in all the ranges flanking the bolsons and forms a significant fraction of the exposed rocks. The overlying middle to upper Ordovician Montoya Group, which is also subdivided into a variety of members, consists primarily of limestone and dolomite with some sandstone. It is 300-400 feet thick, and is also extensively exposed in the Franklin, Hueco, Organ, and Sacramento mountains. The middle Silurian Fusselman Dolomite, which consists of up to 900 ft of dolomite and dolomitic limestone, also has significant exposure in the ranges.

These rocks are overlain by a variety of Devonian and Mississippian rocks, including limestones, cherty limestones, and shales (Barnes 1983; Seager et al. 1987; Nelson and Haigh 1958; LeMone 1969a; 1982; 1989; Harbor 1972; McGlasson 1969; Kottowski 1969). These rocks, which include the Helms, Rancheria, Las Cruces, Arcente, Alamagordo-Andrecito, Caballero, Lake Valley Limestone, Percha Shale, Ocate, and Cantunillo Formations, achieve a total thickness of approximately 650 ft. The Magdalena Limestone (or Magdalena Group) consists of 1,300 to 2,700 ft of Pennsylvanian limestones, shales, and marls (Hardie 1958; Barnes 1983; Seager et al. 1987; LeMone 1969a; 1982; 1989; Harbor 1972). Recognized subdivisions include the Bishops Cap, Berino, and La Tuna Formations in the Franklin Mountains. The Permian Hueco Limestone Group, which includes limestone, dolomite, sandstone, dolomite, shale, and conglomerate, occurs in all of the flanking ranges, where it achieves a total thickness of up to 2,200 ft (Barnes 1983; Seager et al. 1987). It is commonly subdivided into a number of formations, including the Alacran Mountain, Cerro Alto, Hueco Canyon, and Powwow Conglomerate Formations. Thick terrigenous clastic and evaporitic rocks of Permian age, including the Pendejo siltstone, Abo Sandstone, and Yeso Formation, are common in the Sacramento and San Andres mountains, but generally interfinger with the Hueco Limestone and pinch out to the south. Because the Yeso

Formation, in particular, is a prominent source of evaporitic minerals, this transition is partly responsible for the marked difference in the amount of gypsum in the Cenozoic Tularosa and Hueco Basin fills (although more important differences include a higher degree of internal drainage, and hence evaporite formation, in the Tularosa, and the plentiful ancestral Rio Grande stream deposits in the Hueco).

The thick Paleozoic sequence is occasionally capped with thin, sparsely preserved Cretaceous rocks in the Franklin Mountains. The majority of these thin Mesozoic rocks in the ranges have long since been eroded away, if they were ever present. Cretaceous age rocks, primarily of the Washita series, are preserved at the top of the graben blocks in the Hueco Bolson. These rocks were originally deposited in the Chihuahua Trough, which is an older, northwest-southeast trending, Mesozoic-age basin that lies almost entirely in Mexico (Henry and Price 1985), but were shifted northeast toward the Diablo Plateau by pronounced thrust faulting during the compressional phase of the Laramide Orogeny (Albritton and Smith 1965). These few Cretaceous rocks represent the youngest pre-Laramide rocks in the region. The Tularosa Basin is apparently floored entirely by Paleozoic rocks (Lozinsky and Bauer 1991).

The earliest widely distributed Tertiary rock in the region is the Paleocene Love Ranch Formation, which consists of a pebbly to bouldery conglomerate derived from surrounding Paleozoic and Precambrian rocks during the initial phases of the Laramide Orogeny. By the Eocene, volcanism was initiated in the rift zone, depositing thick extrusive rocks of the Orejon Andesite in the vicinity of the Organ Mountains. Through the middle Tertiary, a wide variety of intrusive and extrusive igneous rocks, including tuffs, rhyolites, basalts, quartz monzonites, granites, and syenitic rocks were emplaced by intrusion and eruption (Seager et al. 1987). The most notable intrusives are associated with plutons forming the middle Organ and Jarilla Ranges, but smaller intrusives are also present in the Hueco and Franklin mountains (Hoffer 1969). Extrusives are concentrated around

the volcanic epicenter of the Organ Cauldron, but ash fall tuffs associated with more distant epicenters are also probably present.

The depositional basins in the region are infilled with a variety of alluvial, eolian, and lacustrine deposits and interbedded volcanoclastics (Hawley et al. 1976; Hawley et al. 1969; Strain 1966; 1969a; 1969b; Akerston 1970; Gustavson 1991; Leonard and Fry 1975; Lozinsky and Bauer 1991) that are generally correlated with rocks of the Santa Fe group (Hawley et al. 1969). They are discussed more fully in the historical overview of Cenozoic landscape evolution presented below.

2.5.2 Structure, Paleotectonics, and Neotectonics

The Tularosa and Hueco bolsons are both structurally complex (Collins and Raney 1991; Lozinsky and Bauer 1991) and cut with numerous normal faults (Figure 6). The Tularosa Basin consists of two north-trending half-grabens bounded by the San Andres, Organ, and Artillery Range fault zones on the west and the Alamogordo and Otero fault zone on the east, and separated by a series of buried faults termed the Jarilla fault zone, which trends north-south in the basin west of the Jarilla Mountains. The eastern half-graben dips to the east, while the deeper western half-graben dips to the west (Figure 7). The basin fill attains maximum thicknesses of at least 4,000 ft (1,200 m) at the eastern side of the eastern half-graben, and at least 6,000 ft (1,800 m), and possibly as much as 8,000 ft (2,450 m), at the western side of the western half-graben (Lozinsky and Bauer 1991; Jacobs et al. 1979), but is somewhat shallower in the southern basin, particularly in the eastern half-graben (cf. Figure 7).

The Hueco Basin is also a graben complex, bounded by and cut with numerous normal faults, including the East Franklin Mountains Fault on the western boundary and several unnamed faults on the eastern boundary (Figure 8). Once again, the thickness of Cenozoic basin-fill sediments on the western side of the structural trough is considerably greater than on the eastern side. In

the northwestern Hueco Basin, the basin fill adjacent to the Hueco Mountains is relatively thin (150 to 200 m, or 500 to 650 ft), but adjacent to the Franklin Mountains, the fill is extremely thick (up to 2,750 m, or almost 9,000 ft) (Collins and Raney 1991). These two very different depocenters are separated by a series of unnamed, west-downthrown faults in the medial part of the basin (cf. Figure 6). These faults represent a continuation of the Jarilla fault zone in the Hueco Basin.

Normal faulting is continuing in both basins, and Cenozoic sediments in the basins and on the mountain piedmonts exhibit a number of offset fault scarps (Seager 1980; Machette 1987; Gile 1987a; Collins and Raney 1991). Several examined faults in the northwest Hueco basin offset middle Pleistocene surficial sediments between 2 and 5.5 m, while the very strongly offset East Franklin Mountain fault exhibits more than 25 m of movement since the middle Pleistocene (Collins and Raney 1991).

Despite the fact that the region is generally considered relatively tectonically quiescent, detailed investigation in the eastern margin of the basin and range province documented more than 300 relatively shallow, low-magnitude ($m_l < 3.7$) earthquakes between 1976 and 1979 (Dumas 1980), demonstrating that the area is still tectonically active. Most investigators (e.g., Muehlberger et al. 1978; Seager et al. 1984; Stevens and Stevens 1985; Morgan et al. 1986; Collins and Raney 1991) conclude that faulting in the region is both episodic and ongoing, and that long periods of relative quiescence are occasionally punctuated with significant fault movements. Although the timing of individual episodes of fault activity are generally difficult to determine (Collins and Raney 1991), individual fault movements can sometimes be isolated using a combination of radiometric, sedimentologic, and soil-geomorphic information (Seager 1980; Machette 1987; Gile 1987a). Perhaps the best-documented local example is a movement of the Organ Mountains fault that resulted in about 5 m of vertical displacement around 1000 BP (Gile 1987a), which

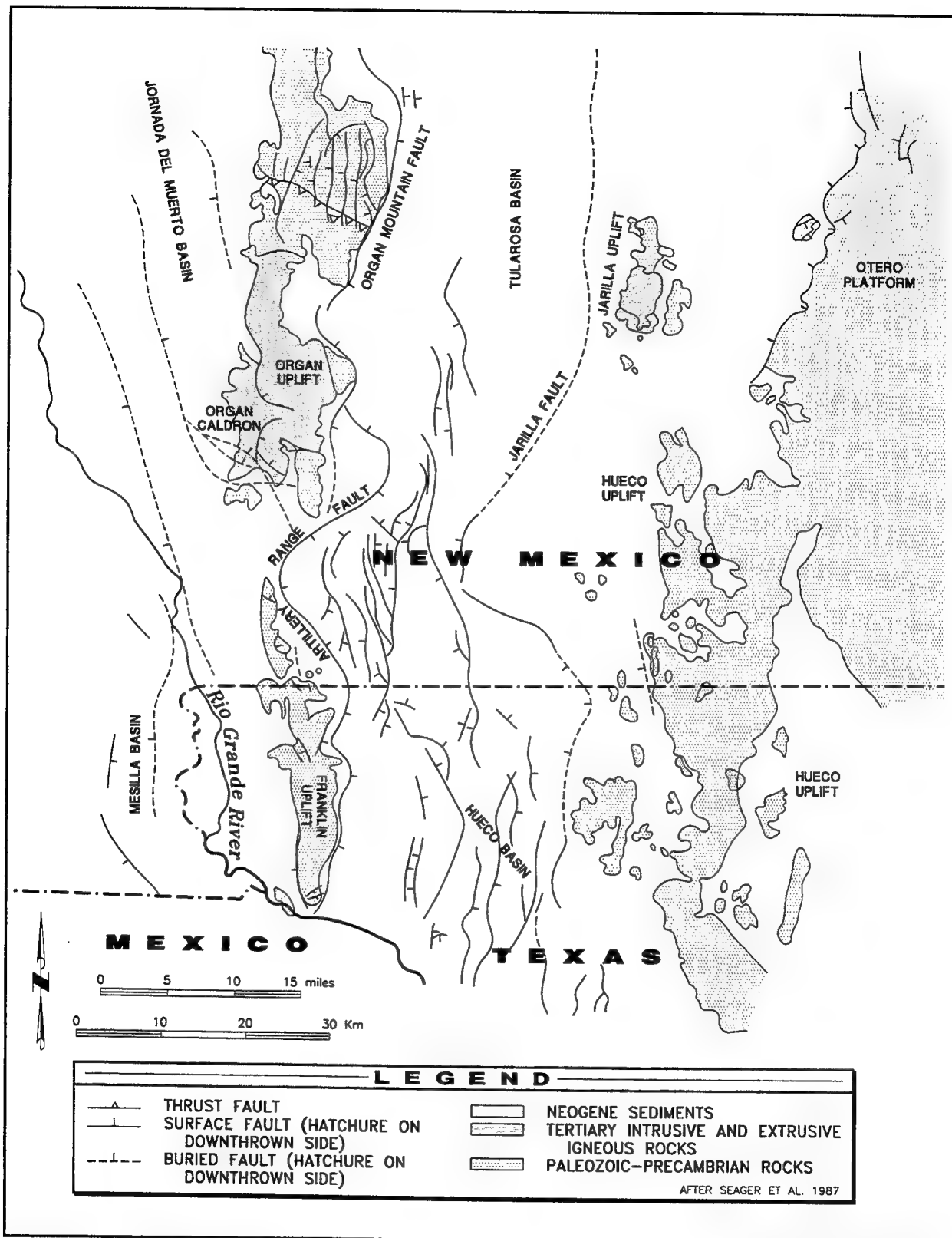


Figure 6 Tectonic Map of the Fort Bliss Region. After Seager et al. 1987, Barnes 1983, and Collins and Raney 1991.

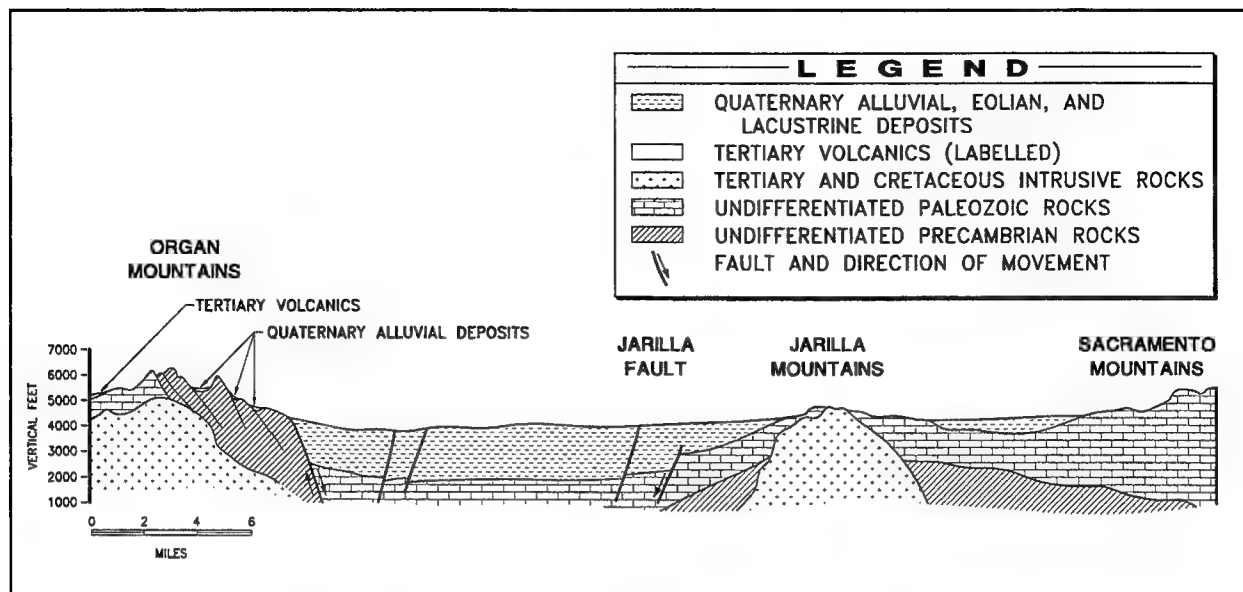


Figure 7 Schematic Cross-section of the Southern Tularosa Basin. After Seaman et al. 1988.

clearly demonstrates that Holocene age fault movements have occurred in the culturally relevant timescale.

Neotectonic faulting has a number of implications relevant to study of prehistory. As Monger (1993a) notes, intragaben fault zones provide localized depocenters and may be the locus for subsequent lacustrine (i.e., playa) and eolian deposition. Because this deposition occurs in areas where surficial sediments are downdropped, the sediment that accumulates is relatively protected from subsequent erosion, and thus apt to preserve a relatively intact record.

Fault scarps also tend to provide an outlet for soil water and ground water in the form of springs and seeps, especially when a subsurface calcic horizon is exposed. Meteoric water infiltrating through the surficial sediment mantle tends to be blocked by a relatively impermeable calcic horizon, and flows laterally downslope within the subsurface sediments above the impermeable horizon. If the line of flow is interrupted by a fault block, that water will tend to emerge at the elevation of the impermeable zone on the exposed face of the fault. Although deposition can quickly bury the scarp, available water can frequently still be obtained with rapid excavation.

Finally, faulting can drastically affect the configuration of the distributory drainage net on alluvial fan surfaces by diverting lines of flow. If a water management system is in place to divert runoff to specific parts of the fan for use in dryland agriculture or horticulture (cf. Leach, Almaraz, Buck, and Burgett 1993), disruption of drainage net by faulting could conceivably strongly affect the function of such a system. However, the frequency of this type of effect was probably extremely low, and would have been far overshadowed by changes resulting from the intrinsic evolution of drainage on the fan surface. If such a tectonic event occurred, it is likely that the direct impact of the seismic shock and related mass movements in the basin and on the surrounding ranges on the population would far outstrip the impact of fresh scarp development on a rudimentary agricultural infrastructure.

2.6 HISTORICAL GEOLOGY AND LATE CENOZOIC STRATIGRAPHY

The modern configuration of the Fort Bliss region is due to compression and subsequent extension associated with the Laramide Orogeny. The timing of initial Laramide compression is poorly understood, but appears to have begun no earlier than the late Cretaceous (Collins and Raney 1991).

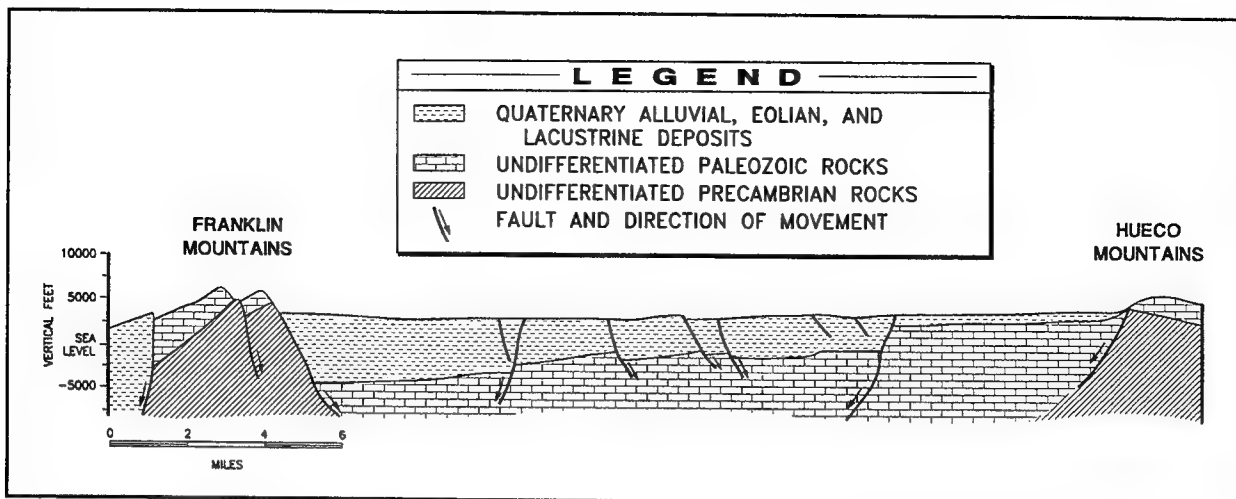


Figure 8 Generalized Cross-section of the Northern Hueco Bolson. Modified from Collins and Raney 1991. Note differences in vertical scale between Tularosa and Hueco cross-sections.

This compression had a number of effects, including thrust faulting and folding of Paleozoic and Precambrian rocks (cf. thrust fault in the southern San Andres Mountains, Figure 6), and large-scale thrust faulting of Cretaceous rocks deposited in the Mesozoic Chihuahua trough, which were detached from underlying Triassic evaporites and thrust northward toward the Diablo Plateau (Albritton and Smith 1965; Collins and Raney 1991). This compressive stress was waning by 50 million years ago (Price and Henry 1985), and gave way to extensional stress by about 30 million years ago in the Oligocene-Miocene (Henry and Price 1989; Collins and Raney 1991). As regional compression waned through the Eocene, volcanic activity in the region increased, resulting in the emplacement of a number of intrusive igneous bodies, including the Organ batholith, the Jarilla pluton, and a number of smaller plutons, dikes, and sills in the general area of Fort Bliss. This activity continued through the Eocene and Oligocene into the early Miocene. Extrusive lavas and volcanics in the region are also associated with this general period of time (approximately 48 to 17 million years ago), although the peak in volcanic activity appears to have occurred 38 to 28 million years ago (Henry and Price 1985; Henry and McDowell 1986; Henry et al. 1986; Seager 1981). Associated tectonic activity, such as the structural subsidence of the volcanic Organ

cauldron (Seager 1975; 1981; Seager and Brown 1978), also occurred during this period of volcanism.

Extensional stress developed in the Oligocene, and initial rifting was progressing by the early Miocene (approximately 24 million years ago), forming the basin-and-range province as normal faults developed and blocks were downthrown (Henry and Price 1985). This faulting has continued episodically to the present, and resulted in fault offsets of up to 3,000 m. Although the timing of accelerated fault movement is not well constrained, Stevens and Stevens (1985) identify accelerated periods of movement around 24 to 17, 10, and 7 million years ago in Trans-Pecos Texas, and it is likely that the timing of increased activity in the Fort Bliss area was similar. The modern landscape is dominated by the effects of this extensional faulting.

As the bolsons of the basin-and-range province developed through the late Tertiary, a variety of colluvial, alluvial fan, fluvial, and lacustrine sediments began to accrete in the deepening basins (Figure 9). During most of this time, the basins were largely closed depressions. The basin-fill sediments in these depressions, collectively termed the Santa Fe Group (Hawley 1969; Gile et al. 1981; Gustavson 1991), were derived from local

material shed off the surrounding mountains. The Hueco Bolson is infilled with up to 3,000 m of clastic material (Collins and Raney 1991), most of which remains unexamined except through remote means such as seismic and gravity investigation. Although the deep-basin fill is relatively poorly understood (Collins and Raney 1991), two formations are identified in the upper basin fill. The older and thicker of these formations is termed the Fort Hancock Formation (Strain 1966). It is composed primarily of lacustrine and alluvial fan deposits with very little fluvial deposition evident, suggesting that it accumulated in a closed basin (Albritton and Smith 1965; Strain 1966; 1969a; 1969b; 1980; Gustavson 1991). In the Tularosa Basin, the deeper basin deposits are typically referred to simply as Santa Fe group (Lozinsky and Bauer 1991; Hawley et al. 1976), although these deposits are sometimes correlated with the Fort Hancock formation (Collins and Raney 1991 Figure 2; Pigott 1977) or the Rincon Valley and Hayner Ranch formations in the Jornada-Rincon-Palomas basins (Gile et al. 1981). Strain (1971) does not recognize the Tularosa Basin as a separate entity, and maps the entire Tularosa-Hueco complex as the Hueco Basin; however, it appears likely that the two basins were discrete depocenters during the accumulation of Fort Hancock and equivalent sediments. In any case, the deep Tularosa Basin deposits are similar in character to the deposits in the Hueco basin.

However, approximately 4 to 3.5 million years ago, the closed basins were successively breached and the Rio Grande became a through-flowing stream in southern New Mexico (Seager et al. 1984), resulting in long-distance sediment transport and a shift from dominantly lacustrine and fan sedimentation to widespread fluvial sedimentation (Gustavson 1991). The deposits resulting from this shift are termed the Camp Rice formation (Strain 1966), which underlie the surface of the bolson floor and associated fan-piedmont surfaces on the margin of the basin. As the Camp Rice bolson floor rapidly aggraded, the more slowly accreting alluvial piedmont deposits on the bolson margins were buried by the expanding level basin floor. Camp Rice sediments have been dated to the late

Pliocene to early Pleistocene through paleomagnetism (Vanderhill 1986) and the inclusion of the Huckleberry Ridge Ash of the Pearlette Ash family (Gile et al. 1981).

Strain (1971) outlines a sequence of events that occurred during integration of the bolsons. Prior to integration of the drainage net, water entering the basin and range from the north (e.g., the ancestral upper Rio Grande) and the south (e.g., the eastern Sierra Madre) accumulated in the basins as lakes, which were sometimes shallow and ephemeral at and other times relatively deep and extensive. As the basins accreted, the topographic divides between various basins were surmounted, and a vast lake, termed Lake Cabeza de Vaca by Strain (1966, 1971) developed in the Mesilla, Hueco/Tularosa, and Bolson de los Muertos in northern Chihuahua (which should not be confused with the Jornada del Muerto in south-central New Mexico). This lake was fed primarily by the ancestral Rio Grande, which delivered meltwater from the southern Rockies, and attained an elevation of at least 1,234 m (4,050 ft) and possibly as much as 1,295 m (4,250 ft) in the Hueco Bolson (Strain 1971; Gustavson 1991).

In Strain's model, integration of the bolson segments proceeded upstream through either overtopping of topographic divides by the lake, which stimulated erosion of the drainage divides, or by headward cutting of tributaries of the ancestral lower Rio Grande, or both. This model suggests that the divide between the Hueco Bolson and the Red Light Bolson was breached first, initiating significant erosion of Fort Hancock strata in the southern Hueco Bolson and deposition of the Camp Rice strata.

On the basis of constraining faunal and paleomagnetic ages for the upper Fort Hancock and volcanic ash in the lower Camp Rice, Gustavson (1991) argues that the Hueco Bolson was integrated into the lower Rio Grande drainage system by approximately 2.25 million years ago, implying that Lake Cabeza de Vaca was a phenomenon of the latter Pliocene. This is considerably older than Strain's (1966, 1971)

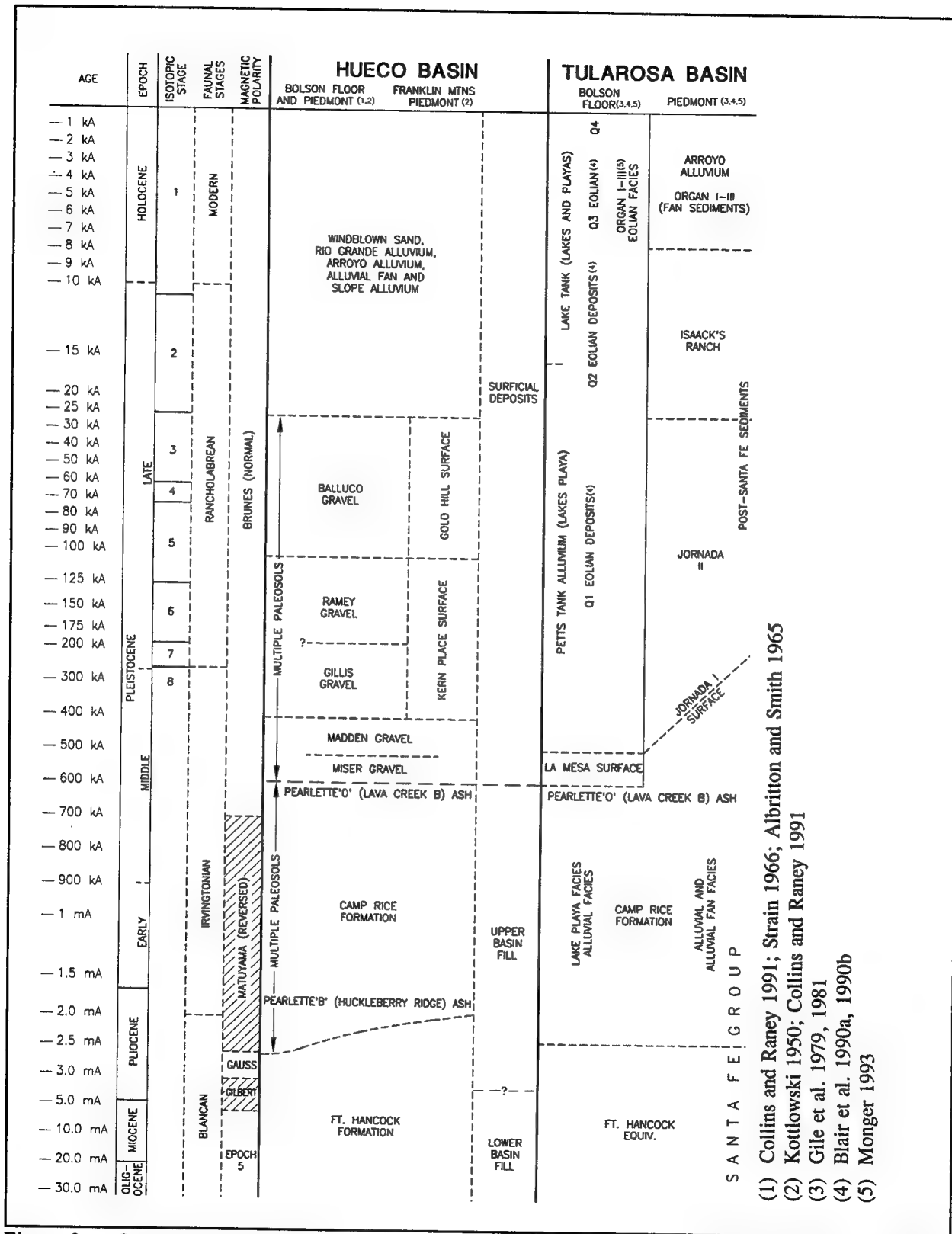


Figure 9 Quaternary Stratigraphy of the Hueco and Tularosa Basins. Adapted from Gile et al. 1981 and Collins and Raney 1991.

previous interpretation that it was of middle Pleistocene age, which was a result of imperfect understanding of the provenance of the Pearlette family ash in the lower Camp Rice (Gustavson 1991). Somewhat later, the divide between the Mesilla and Hueco Bolsons was breached, draining the remainder of Lake Cabeza de Vaca. However, smaller lakes, including Lake Otero in the Tularosa Basin (Herrick 1904; Blair et al. 1990a) and Lake Palomas in the Bolson de los Muertos (Reeves 1965; 1969), were intermittently maintained as pluvial lakes within the boundary of Lake Cabeza de Vaca through much of the Pleistocene. Relict gravel deposits in Fillmore Pass, between the Franklin and Organ mountains, suggest that the ancestral Rio Grande flowed here, rather than between the Franklin and Juarez mountains, at one point (Strain 1966; 1971; Seager 1981). Although Hawley (1981) suggests that this high channel represents the remnant of an integrated Pliocene drainage (in a sense, a true ancestral Rio Grande) that was disrupted by renewed tectonism and range uplift (presumably in the late Pliocene), others (e.g., Seager 1981; Blair et al. 1990a) have suggested that the Fillmore Pass alluvium represents Rio Grande alluvium post-dating Lake Cabeza de Vaca. The mapped distribution of Camp Rice fluvial facies in the southern Tularosa Basin (Seager et al. 1987) suggests that the Rio Grande drainage may have been diverted back into the Tularosa Basin at some time in the middle Pleistocene, forming or contributing to Lake Otero (Blair et al. 1990a). In either case, the conduit between the Mesilla and Hueco Bolsons shifted to its present position south of the Franklins in Paseo del Norte prior to entrenchment of the modern Rio Grande roughly 600,000 years ago.

As integration of the Rio Grande drainage progressed through the Quaternary, the stream became a more efficient conduit and basin-wide aggradation gave way to incision of the modern Rio Grande valley, effectively terminating the deposition of the Santa Fe Group/Camp Rice Formation and forming the La Mesa geomorphic surface on the level bolson floor (Gile et al. 1981). Associated geomorphic surfaces/morphostratigraphic units on the

fan-piedmont include the older Doña Ana and younger Jornada I piedmont surfaces, which are underlain by piedmont facies (i.e., alluvial fan sediments) of the Camp Rice. Both of these constructional surfaces formed prior to entrenchment of the Rio Grande and are considered part of the Santa Fe Group.

The Doña Ana and Jornada I surfaces exhibit very strong soil development, suggesting that they were stable for a considerable period of time. However, active fan deposition continued into the late Pleistocene in the form of broad piedmont alluvium termed the Jornada II in New Mexico (Gile et al. 1981). Roughly equivalent deposits in Texas have been divided into a series of fan and piedmont sediments termed, in order of decreasing age, the Miser, Madden, Gills, Ramey, and Balluco Gravels (Collins and Raney 1991). Monger (1993b) adapted the terminology of Gile et al. (1981) to the deposits on Fort Bliss, and this terminology is also employed here.

Jornada II deposits reflect a basinward shift in the locus of deposition as the proximal fans were trenched and bypassed, resulting in a thin, broad mantle of gravelly sediments prograding out over the distal Jornada I surface and onto the basin floor. At the same time, activity on the margin of the entrenching Rio Grande valley led to the formation of a series of distinct pediment and terrace surfaces, including the Kern Place surface and the Gold Hill surface, inset against the Franklin Mountains and the elevated plain formed by the bolson floor (Kottlowski 1958). The proximal Jornada I and Doña Ana piedmont, bypassed by incised fan channels, continued to subaerially weather, and were subject to slow lateral dissection throughout this period. On the bolson floor, fine-grained alluvium termed the Petts Tank alluvium began to accumulate in depressions on top of the La Mesa surface (Gile et al. 1981).

The Late Pleistocene and Holocene saw renewed alluvial fan deposition and an increase in eolian activity on the piedmont and basin floor. Several morphostratigraphic units/geomorphic surfaces of

this age are identified in the region. The Isaack's Ranch morphostratigraphic unit/geomorphic surface consists of alluvial fan/piedmont alluvium that began to accrete sometime during the very late Pleistocene after a period of relative quiescence and soil formation following cessation of Jornada II deposition (Gile et al. 1981). Like Jornada II, the Isaack's Ranch alluvium generally bypassed the more proximal older piedmont surfaces in entrenched channels, then spread out as fan deposits over the distal older fans. The Isaack's Ranch unit remains poorly dated, but appears to correspond to the last full glacial through late glacial; in any case, deposition terminated by the early Holocene (approximately 7,000 year ago). Isaack's Ranch alluvium typically consists of relatively narrow, confined channels and associated unconfined sheet deposits of gravelly alluvium typically bounded by Jornada II deposits. Associated fine-grained deposits on the basin floor are termed the Lake Tank unit; other than a much less-pronounced degree of soil development, they are very similar to the earlier Petts Tank deposits (Gile et al. 1981; Monger 1993b). Monger (1993b) also identifies an Isaack's Ranch eolian unit, which is characterized by the development of an argillic horizon and well-developed Stage II carbonate morphology (i.e., distinct, relatively large carbonate nodules). Frequently, the Isaack's Ranch eolian unit is erosively truncated, leaving a lag of these nodules strewn across an exposed or buried truncation surface.

The majority of the Holocene is characterized by continued deposition of the Lake Tank unit in depressions on the La Mesa surface and by deposition of the Organ morphostratigraphic unit on the piedmont and, as eolian sands, on the basin floor. Like the preceding piedmont units, the Organ Alluvium generally bypassed the older proximal fan sediments in entrenched channels, but buried distal elements of the older units under fan and sheet alluvium. An idealized block diagram illustrating architectural relationships between these major depositional units is presented in Figure 10.

The Organ unit was originally defined as alluvial fan and piedmont alluvium by Ruhe (1964, 1967)

but has since been expanded to also encompass eolian facies on the fans and basin floor (Monger 1993b). Organ alluvial deposition has been subdivided into three phases (termed Organ I, II, and III) that span the period from 7000 BP to immediately before the historic period (Gile et al. 1981). Monger (1993e) identifies three eolian phases and equates them both terminologically and temporally with the previously identified Organ alluvial sequence. Organ I sands were deposited between 7000 and 2100 BP, and exhibit moderate to good Stage I carbonate development and weak argillic development. Organ II was deposited between 2100 and 1100 BP and exhibits very faint Stage I morphology. Organ III was deposited from 1100 to 100 BP and exhibits no real pedogenic modification except formation of an A horizon (frequently absent due to erosive truncation) and bioturbation, which has eliminated evidence of primary bedding. A final series of deposits of historic age, including arroyo alluvium and extensive sheet sands, partially vegetated mounded and ridgelike dunes, and mounded coppice dune sands, are nearly ubiquitous in the basin, particularly on the bolson floor. These deposits appear to represent the response of the landscape to grazing following Euroamerican settlement of the region in the latter half of the nineteenth century. Historic eolian deposits are easily distinguished in section because they exhibit distinct primary crossbedding.

Because they are the sediments of culturally relevant age on Fort Bliss, Organ and post-Organ sediments, and to a lesser extent the sediments of Isaack's Ranch age, are of primary interest in this study, and will be addressed in a greater level of detail in the treatments of eolian and alluvial sediments (Sections 6.1 and 6.2). Note that these units, which are defined on the basis of criteria that integrate stratigraphic, soil-stratigraphic, and lithologic evidence with geomorphic surface expression do not necessarily correspond to the landform classification based on aerial photo signatures developed by Satterwhite and Ehlen (1980) (see Section 2.1).

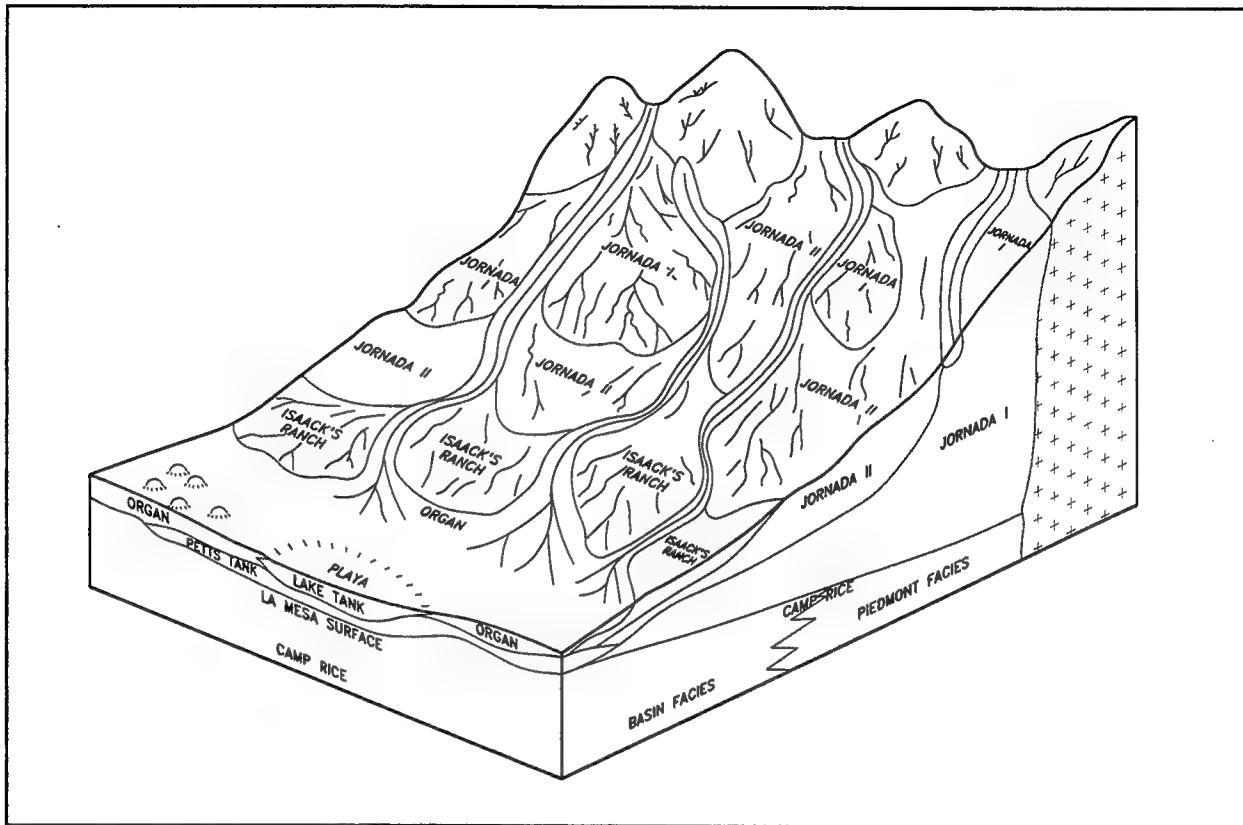


Figure 10 Block Diagram Illustrating Relationships Between Morphostratigraphic Units in the Bolson. Modified from Monger 1993a.

2.7 HYDROLOGY

Surface water on Fort Bliss is rare and ephemeral. However, due to the steep slopes, shallow soils, and poor plant cover, runoff from the occasional heavy precipitation events can be very heavy, and surface drainages can rapidly become swollen and very active. In this environment, geomorphic activity is strongly punctuated; it is likely that well over 99% of the work done by water occurs during strong storms that span much less than 1% of the time.

In general, surface drainages on Fort Bliss head as dendritic catchments in the mountains flanking the basin and emerge from the mountain front onto large, moderately sloping alluvial fan surfaces. These drainages tend to cut through the upper fans in incised arroyo channels before emerging into dendritic distributary channel networks on the distal fan surfaces. Thus, the drainages can be

subdivided into three basic zones: a zone of erosion and entrainment, situated in the mountains; a zone of sediment bypassing where transport is relatively efficient in the channelized upper fans; and a zone of deposition, where the incised channel gives way to a dendritic distributary network of shifting, less-competent channels on the lower fan. In general, the distributary network of minor channels tends to die out before reaching the basin floor. In the basin, surface water is limited to the playas (see Figure 3), which are typically dry but can maintain standing water for days or sometimes weeks at a time following storms.

Like other basins in south-central New Mexico (Leggat et al. 1963), ground water in the Tularosa/Hueco Bolson is associated with aquifers in basin-fill sediments (Meisner and Hare 1915), particularly the Camp Rice and Fort Hancock Formations (Knowles and Kennedy 1956; Cliett 1969). Brackish groundwater can occur within a

few hundred feet of the bolson floor, and becomes increasingly mineralized with depth. Some fresh water is available in the Camp Rice Formation, particularly adjacent to the Franklin Mountains, while water in the Fort Hancock Formation is highly saline. In general, this groundwater was completely unavailable to the prehistoric population and to plants. However, some shallow subsurface water was occasionally available to plants following rains due to the presence of the strongly developed La Mesa and Jornada calcretes, which effectively prevent deep infiltration. Although probably not often utilized as a source of drinking water, this ephemeral subsurface water would have been very important to wild plant production in the arid environment.

2.8 PALEOCLIMATE AND PALEOENVIRONMENT

At best, the paleoenvironmental conditions affecting the Fort Bliss region throughout the culturally relevant period are imperfectly understood, and much more basic research is needed to clarify the sequence of climatic and environmental change. Three basic avenues of information provide a basis for clarifying the paleoenvironmental record. First, instrumental records of historic patterns in temperature and precipitation provide a baseline for understanding deviation from the modern "norm" during the prehistoric period (see Section 2.2). Second, a variety of types of proxy evidence that describe the landscape response to changes in climate can be employed to infer paleoclimatic conditions (Bradley 1985; Lowe and Walker 1984). Proxy sources of paleoenvironmental information relevant or potentially relevant to the Fort Bliss region are addressed in detail in Chapter 6.0. Finally, conceptual and numerical models of atmospheric dynamics and global circulation can be used to infer the mechanisms dictating the character of climate and climate change (Bryson et al. 1970; COHMAP Members 1988; Kutzbach et al. 1993).

Collectively, paleoenvironmental data from the Fort Bliss region present a picture of a stable, mesic terminal Pleistocene, followed by steadily

increasing aridity through the Holocene. Figure 11 summarizes several paleoclimatic reconstructions from Fort Bliss and surrounding areas.

The Late Pleistocene full glacial was apparently a time of relatively cool, moist conditions, with widespread coniferous and mixed coniferous-deciduous woodlands. The entire region seems to have supported piñon-juniper-oak woodland, while Douglas fir was present at elevations as low as 1,200 m (3,850 ft) (Van Devender 1990). On the other hand, insect data from packrat middens suggests that a well-developed grassy understory was present from at least 18,000 BP (Elias and Van Devender 1992). No modern Chihuahuan desert taxa appear to have been present (Van Devender et al. 1984). A Full Glacial (approximately 18,000 BP) faunal record from Dry Cave in southeastern New Mexico includes small mammals (e.g., prairie vole, least shrew) that occur now on the northern Great Plains, suggesting that winter precipitation was greater and temperatures were cooler, particularly in summer (Harris 1989; 1990). Lake levels from the San Agustin Plain in west-central New Mexico indicate that precipitation was high enough and evapotranspiration low enough to maintain a deep, permanent lake (Markgraf et al. 1984).

In Late Glacial time (approximately 12,000 BP), the piñon-juniper forest continued to persist throughout the region, but the northward migration of a few cold-intolerant plants suggests that conditions were beginning to ameliorate, and particularly that the incidence of hard winter freezes was declining (Van Devender 1990). By about 12 ka, effective moisture was also decreasing, resulting in gradual disappearance of mesic woodland species (e.g., Douglas fir, Rocky Mountain juniper) at the expense of more xeric species (e.g., piñon pine, one-seed juniper) between approximately 11,500 and 10,000 BP. At about the same time, xeric insect species began to appear at the expense of temperate species (Elias and Van Devender 1992).

By the early Holocene (approximately 9000 BP), the transition from a mesic environment to a xeric

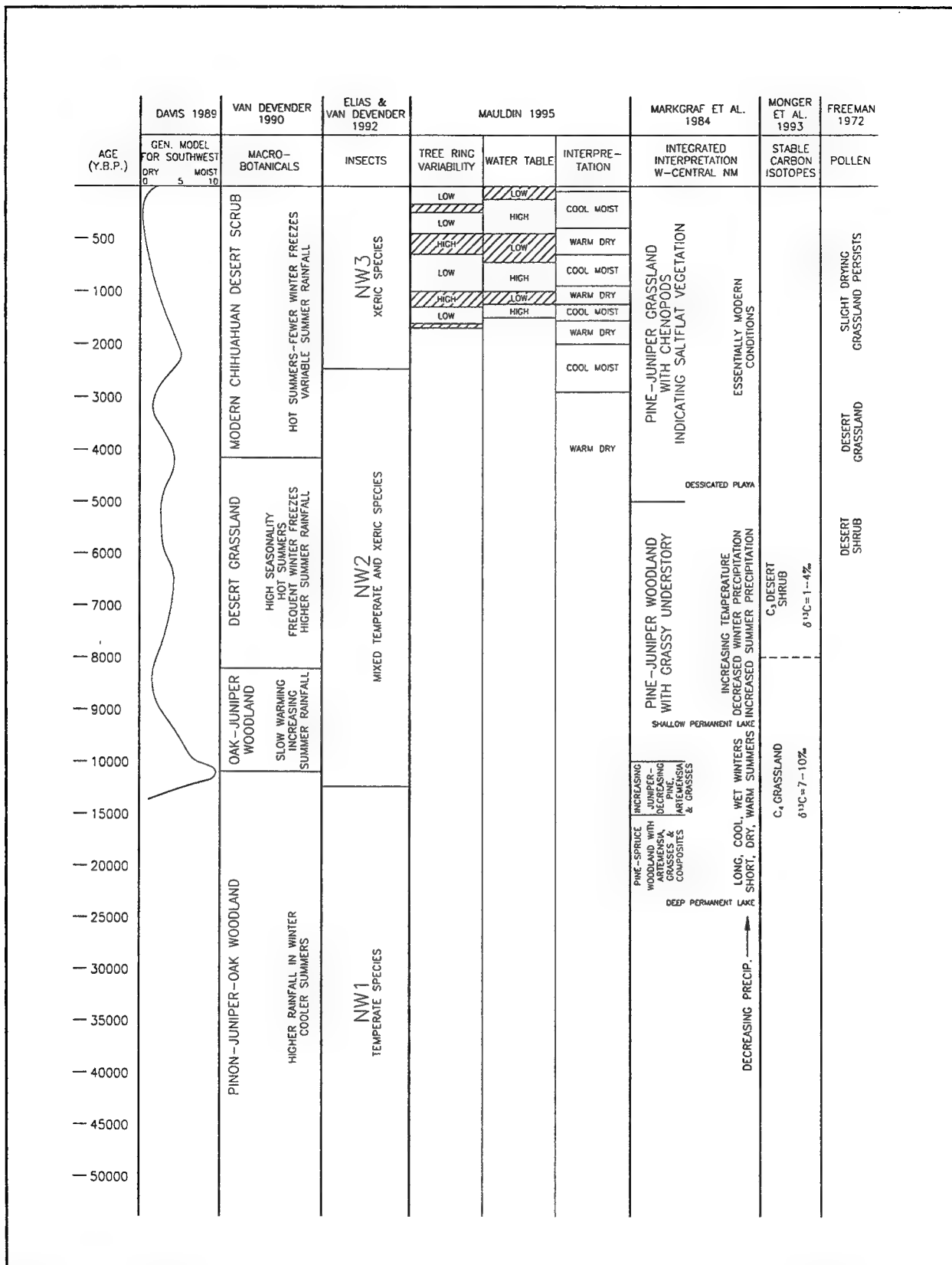


Figure 11 Summary of Paleoenvironmental Data from the Southern New Mexico Region.

environment was well underway in the vicinity of Fort Bliss. Packrat midden data from the Sacramento Mountains indicate that Douglas fir and Rocky Mountain juniper had disappeared, leaving a piñon pine-juniper-oak woodland, which persisted until about 8000 BP, when it was replaced by desert grassland (Van Devender et al. 1984). In the Hueco Mountains, piñon pine disappeared by 10,800 BP (Van Devender 1990). The next few thousand years were dominated by a transitional woodland as the community continued to shift toward drier conditions. Van Devender (1990) interprets the changes as indicating that while winter rains were still dominant, summer precipitation increased to up to 40% of the annual total.

A clear transition toward a xeric community is indicated by about 8000 BP. Vegetation shifts in the region include the appearance of desert scrub and succulents, including *Opuntia* spp. and honey mesquite, and the complete disappearance of temperate taxa. Arthropods also document the establishment of desert grassland conditions in the Hueco Mountains (Elias and Van Devender 1992), while stable carbon isotopes of pedogenic carbonates in the bolsons suggest a strong shift from C-4 grasslands toward C-3 desert scrub plants (Monger et al. 1993). Van Devender (1990) argues that the shift at 8000 BP represents the onset of dramatically higher summer temperatures, continued frequent winter freezes, and a shift to dominantly summer precipitation. Somewhat later (approximately 7000 BP), geomorphic activity on the alluvial fans (Gile et al. 1981) and in the bolsons (Monger 1993b; Blair et al. 1990a) increased markedly, presumably in response to these climate changes.

By about 6000 BP, desert species such as mesquite and sotol were well established, but cold-sensitive Chihuahuan Desert taxa (e.g., lechuguilla) were generally absent, presumably due to continued severe winter freezes, and xeric grasslands were still widespread. Mesic plant and insect taxa were still present, but in low numbers. Lakes in west-central New Mexico suggest that by 5000 BP, the Pleistocene pluvial lakes had been replaced by dessicated playa pans (Markgraf et al. 1984). By

about 4000 BP, all of the modern Chihuahuan desert scrub taxa were present (Van Devender 1990), albeit possibly in relative frequencies and distributions dramatically different than at present, and the last of the temperate arthropod species disappeared by about 2500 BP (Elias and Van Devender 1992). From this point, major changes in biota are not apparent. However, variations in stream activity (i.e., episodes of aggradation and incision) and fluctuations in tree ring widths suggest that smaller scale fluctuations in climate continued to occur throughout the last few thousand years. Although grasslands in the mountains appear to be replaced by desert scrub by roughly 4000 BP, the configuration of the eolian sand sheets in the bolson suggest that they were probably deposited in an environment with some grassy groundcover. However, stable carbon isotopes reflect continued dominance of C-3 scrub vegetation throughout the late Holocene (Monger et al. 1993).

In summary, the paleoenvironmental record in the vicinity of Fort Bliss reflects a basic trend toward increasingly warm and arid conditions throughout the Holocene, culminating in an arid environment that would have yielded resources grudgingly. This record is primarily composed of evidence on the presence or absence of diagnostic taxa. However, it is likely that smaller scale fluctuations, such as are evident in the relatively short tree ring record, were superimposed on this long-term trend. While not resulting in the extirpation of diagnostic taxa, it is likely that these smaller fluctuations had significant impacts on the abundance and distribution of water, plants, and animals that would have required adjustments in cultural systems designed to optimally exploit the marginal environment.

3.0 PREVIOUS RESEARCH IN THE REGION

Raymond Mauldin

This section provides an overview of previous research in the southern, or lowland section, of the Jornada area around El Paso, Texas. This review is extensive, though not exhaustive. A large number of archeological projects have been conducted within the region since the early 1970s, and it is not feasible to review all of these investigations. Our review of work conducted after 1970, therefore, focuses on investigations on Fort Bliss, on larger projects outside of the reservation, and on projects that have synthesized the overall state of research in the southern Jornada area.

The first section of this chapter introduces the phase system commonly used in the lowland Jornada area and provides a synthesis of the current understanding of cultural history in that region. The next two sections provide a brief historical perspective on the development and implementation of culture history models in the region, and the final section summarizes recent developments in the region.

3.1 CURRENT CULTURAL HISTORY MODELS

Currently, the archeological systematics used to synthesize the organization of cultural systems across space, and account for how these systems change through time, is a variation of cultural history models developed in the 1940s (see Lehmer 1948). While a variety of alternative schemes have been suggested for the southern Jornada area, most of these essentially rely on variations in artifact type or architecture on a site to assign the site, or components within a site, into temporal phases. Table 6 provides a summary of cultural periods, phases names, chronological time periods, and diagnostic artifacts and architectural characteristics commonly used in the region.

The earliest accepted occupation in the area is associated with Paleoindian (11,000 to 8000 BP)

occupations, though MacNeish et al. (1993) have recently claimed the recovery of material from Pendejo Cave in the Otero Mesa area; they argue this material dates prior to 35,000 BP. Paleoindian occupations are represented primarily by isolated finds of projectile points and a small number of open sites in the Tularosa Valley (see Amick 1994; Beckes 1977a; Carmichael 1986a; Krone 1975).

Relative to later periods, little is currently known of the Paleoindian occupations in the region. While at least 100 whole and fragmentary Clovis points have been recovered from the large Mockingbird Gap Site (Weber and Agogino 1968), and late Paleoindian (e.g., Plano/Cody) finds have been reported in the region (HST 1973), there are no well documented sites for either end of the Paleoindian temporal span, and little is known about Paleoindian adaptations. At present, it is not clear whether this reflects actually sparse use of the region during the period, or if it is a result of problematic diagnostic criteria.

The Folsom manifestations of the Paleoindian period is well represented in the Tularosa Valley by both isolated projectile points and several Folsom sites (see Amick 1991, 1994; Carmichael 1986a; Beckett 1983; see also Mauldin and O'Leary 1994). In an exhaustive review of Folsom assemblages from the region, Amick has argued that the Tularosa Folsom material represents only a component of a large scale mobility system that involves assemblages on the southern Plains. He argues that the Tularosa Valley material represents a residential land-use pattern focused on nonbison game, while the southern Plains was focused on logistical bison procurement.

The Archaic Period (6000 B.C. to A.D. 200) in the El Paso area is better represented in the record. Reports on regional surveys (e.g., Carmichael 1986a), cave excavations (e.g., Cosgrove 1947), and open-site excavation (O'Laughlin 1980; Fields and Girard 1983; O'Laughlin et al. 1988; O'Laughlin and Martin 1989) are available.

Table 6 Summary of Cultural Periods, Phase Names, Chronological Periods, Diagnostic Artifacts, and Architectural Characteristics.

| Time Frame (years BP) | Period Name | Phase | Diagnostic Artifacts / Architectural Characteristics |
|--------------------------|-------------|-----------------|---|
| 11,500 | Paleoindian | Clovis | Lanceolate fluted points |
| 11,000 | Paleoindian | Folsom | Fluted points, endscrapers, Edwards chert |
| 10,000 | Paleoindian | Plano/Cody | Lanceolate points, parallel flaking "Cody" knife, endscrapers |
| 8000 | Archaic | Gardner Springs | Jay and Bajada points |
| 6000 | Archaic | Keystone | Todsen, Amagosa, Shumla points; shallow circular huts |
| 4500 | Archaic | Fresnal | Chiricahua, San Jose, Maljamare, Augustin, Fresnal points; shallow circular huts |
| 2900 | Archaic | Hueco | San Pedro, Hueco, Armijo points; houses similar to Fresnal |
| 1850 | Formative | Mesilla | El Paso Brownware, Mimbres Black-on-white ceramics; pit structures, shallow circular huts |
| 800 | Formative | Dofia Ana | El Paso Bichrome, polychrome, Mimbres, Chupadero Black-on-white ceramics; rectangular pithouses with adobe |
| 700 | Formative | El Paso | El Paso Polychrome, Chupadero, Three Rivers Red-on-terracotta, Gila Polychrome ceramics; adobe rooms, square shallow huts |
| 500 | | | |

Excavations, many of which have been located on Fort Bliss, have documented a substantial Archaic use of the area, especially late in the sequence, although "diagnostic" artifacts are rare. For example, Whalen (1980) excavated a series of hearths from small sites in Maneuver Area 1 that lacked any temporally diagnostic artifacts. Radiocarbon dates from this excavation, when corrected, range from 2480 B.C. to A.D. 939, but most of his 19 dates fall in the Late Archaic and early Mesilla phase. Mauldin, Graves, and Bentley (1994) have recently completed a draft report on

Project 90-11, located in Maneuver Area 1, that also focused on small sites. They suggest, based on a synthesis of radiocarbon dates for the region, that a substantial number of small sites fall in the Late Archaic period. Similarly, the draft reports for the Loop 375 project (O'Laughlin and Martin 1989; O'Laughlin et al. 1988) suggest a substantial Late Archaic focus not revealed by diagnostics.

While an increasing number of dates are available that suggest an Archaic use of the region, models of adaptations during this long period are limited.

MacNeish et al. (1993) have recently outlined a phase sequence and Anderson (1993), relying primarily on survey data generated by Carmichael (1986a), has used that phase sequence to produce a settlement systems model. Anderson (1993) suggests a reduction in mobility through time, increased regional population, and increased seasonality (see also Carmichael 1986a). While cultigens are clearly present in the area by 3000 BP (see Upham et al. 1987; Tagg 1993), most researchers suggest that a broad spectrum adaptation tied to hunting and gathering characterizes the entire period.

The Formative Period (A.D. 250 to 1450) is divided into three phases. These are the Mesilla phase (A.D. 250 to 1150), the Doña Ana phase (A.D. 1150 to 1250), and the El Paso phase (A.D. 1250 to 1450). The Mesilla phase is distinguished from the Archaic by the presence of brownware ceramics. Mimbres Black-on-white wares may come into the area after A.D. 750, though they generally are not common. Although true pithouses occur in the Mesilla phase (Lehmer 1948), most domestic structures associated with this phase are shallow, basin-shaped huts reminiscent of the earlier Archaic period structures (Hard 1983b; O'Laughlin 1980).

Sites became larger during the Mesilla phase and many more Mesilla sites and artifacts have been identified than have their Archaic counterparts. Whalen's (1977, 1978) survey of Maneuver Areas 1 and 2 recorded Mesilla phase sites in all environmental zones. Based on the wide distribution of sites, Whalen suggests that subsistence was derived primarily from hunted and gathered resources. As in the Late Archaic, the diet continued to be supplemented by agriculture. Carmichael's (1986a) survey results do not differ significantly from those of Whalen for the Mesilla phase, supporting Whalen's characterization of this phase.

Associated with his work at Turquoise Ridge on Fort Bliss, Whalen (1994) has recently proposed a Formative site classification. Class 1 sites are large, with large pithouses, extensive site and

structure modifications, evidence of reoccupation, middens, and storage features. Whalen suggests that these are located only along fans or rivers. Class 2 sites are smaller with shallower pit structures. Middens may be present, but there is a lower overall artifact density relative to Class 1 sites. Class 2 sites are located in all environmental zones. Class 3 sites are similar to Class 2 sites, but lack middens and have a variety of other indicators of lower overall occupational intensity. Finally, Class 4 sites are small, lack formal structures, and have low artifact content and diversity. Whalen argues that Class 1 sites represent winter base camps with Classes 2, 3, and 4 reflecting various levels of effort expended on spring/summer provisioning camps. He also notes that the frequencies of Class 3 and 4 sites relative to Class 2 sites seem to change after A.D. 750, with no Class 2 sites observed prior to that date. Conversely, there are fewer Class 3 and 4 sites after A.D. 750. Whalen suggests that this pattern reflects intensification in the collection of nondomesticated resources during the warm season.

Hard (1983a) has outlined a detailed settlement/subsistence model in which environmental differences dictate seasonal rounds and activities. Hard's model shares many characteristics with that of Whalen; Hard argues that winter and spring residential sites are located near the mountain alluvial fans with the central basin used in a logistical manner. During the summer and fall, Hard suggests a use of the central basin for short-term residences. While Hard's research at the Conejo site, a late Mesilla phase occupation located on the Organ Mountain Fans, is not yet completed, initial analysis of that material do not contradict the model (Hard 1983a, 1986, personal communication, 1995).

The Doña Ana phase, first introduced by Lehmer (1948) and extensively employed by Carmichael (1986a; see also Kegley 1982), is essentially equivalent to Way's (1979) designation of the Early Pueblo Period (see also Whalen 1978). Carmichael (1986a) provides the most recent synthesis for this period. Based on survey data, he argues that it was during this 100-year phase that

prehistoric occupational intensity was at its height in the region. While several researchers have questioned the ability of archeologists to distinguish Doña Ana phase occupations from multicomponent occupations given the definitional characteristics (see Mauldin 1993a; Miller 1989, 1993), Hard et al. (1994) have recently argued that this phase can be distinguished with a detailed focus on ceramic attributes. Scarborough (1986, 1992), working at a Doña Ana phase site on Meyer Range, presents the most detailed evidence on this period (see also Miller 1989, 1993). While still unpublished, his study clearly suggests a subsistence base using a variety of plants, including evidence for increased agriculture over the preceding Mesilla phase.

The Late Formative occupation, the El Paso phase, is distinguished from the preceding Doña Ana phase by the continued development of locally made painted pottery (El Paso Polychrome), and an absence of Mimbres Black-on-white as an intrusive. Regional survey data suggest that the most intensive prehistoric use of the region may have occurred during the El Paso phase. This period is marked by more and larger sites, greater artifact densities, and a clustered settlement pattern (Carmichael 1986a; Whalen 1977, 1978). Pueblos are present along the Rio Grande, and both the western and eastern margins of the Hueco Bolson have large El Paso phase settlements. Along the western bolson, Whalen (1977) found that nearly half of the El Paso phase villages were along low gradient alluvial fans, with many additional sites present near alluvial fans with playas. On the eastern margin of the Hueco Bolson, villages associated with alluvial fans are documented as well (Whalen 1978). Whalen suggests that this location, in well-watered areas, hints at an agricultural focus during this period. While direct data on subsistence is limited, ethnobotanical and faunal data from a variety of excavations in the region support Whalen's view. Agriculture becomes important during this period, though wild plants and animals, including fish, continued to play an important subsistence role (Bradley 1983; Foster and Bradley 1984; O'Laughlin 1977a; Foster et al. 1981).

The actual degree of sedentism during the El Paso phase is unclear, as is the pattern of mobility. Mauldin (1986) has developed a settlement and subsistence model for the El Paso phase. Mauldin's model is based on Hard's (1983a) Mesilla phase work, but assumes that agricultural dependence is somewhat greater. He suggests a dichotomy between primary and secondary villages. Primary villages should be located in well watered areas near mountain slopes. Mauldin argues that these sites will have a fluctuating population throughout the year and a high intensity of use. Subsistence is primarily based on agriculture. Secondary villages, located both along mountain slopes and in the central basin associated with playas, represent late summer residential occupations with a focus on gathering and hunting. While several researchers (e.g., Browning et al. 1992) have used the model to describe El Paso phase distributions, it has not been subject to any degree of testing.

Bentley (personal communication, 1995) has recently completed a draft of a manuscript synthesizing over 60 years of excavations at the Hot Wells Pueblo site, a large multi-room pueblo located on the eastern side of Fort Bliss. While unavailable at present, the manuscript should provide important data for the El Paso phase. Similarly, O'Laughlin has conducted extensive excavations at the Firecracker Pueblo site on the lower alluvial fans of the Franklin Mountains. While no manuscript is yet available, this excavation will provide important data that may significantly change the current view of the El Paso phase adaptation in the region (O'Laughlin, personal communication, 1994).

The end of the prehistoric sequence is conventionally placed sometime after A.D. 1450. The large pueblo sites in the southern Jornada were clearly abandoned by this time, perhaps in response to the extended droughts throughout the greater Southwest. Upham (1984) argues that the local populations returned to non-sedentary adaptations. Spanish contact, which did not occur until the sixteenth century, documents the presence of local populations as dependent on limited agriculture and

hunting and gathering (see Beckett and Corbett 1992). These populations are variously described as Manso, Jumanos, and Sumas (see Schroeder 1947). The period between the close of the El Paso phase and the first Spanish contact documenting these populations is not well understood in the region (see Bentley 1992). Thompson and Beckett (1979) report the recovery of metal worked into projectile points and Bentley (1992; see also Beckett and Corbett 1992) provide a summary of known or suspected archeological sites in the region. These semi-nomadic populations were eventually assimilated by the Spanish (see Hammond and Rey 1966; Timmons 1990). Established mission settlements were present by the seventeenth century, and Anglo-American populations were established during the early nineteenth century.

The above-noted phase-based cultural history sequence was developed in the context of past descriptive and explanatory goals. Essentially based on models of cultural expression and change in the 1940s (see Lehmer 1948), this perspective is currently used to reconstruct activities during a given period. These synchronic models are then compared, and differences between them are identified as areas in need of explanation. As will be discussed below, there is some dissatisfaction with the phase-based approach. However, it continues to be used by most researchers to synthesize the archeological record. The rest of this chapter explores how these phase-based systems were developed, and discusses several alternatives to this approach.

3.2 INITIAL ARCHEOLOGICAL RECONNAISSANCE IN THE REGION

Professional archeological investigation in the region generally lagged behind that of both the northern and western Southwest. Much of the earliest work in the area seems to have been conducted by amateurs, and while no formal reports are available for much of this work, reference to such undertakings are occasionally made in published reports in the late 1920s. Several short summaries of archeological work in

the region were presented during the late 1920s and early 1930s. Chapman (1926) reports on pueblo sites on the west side of the San Andres Mountains; Crimmins (1929, 1931) provided short summaries of observations in the region prior to 1929, with special attention on the pictographs and petroglyphs; and Alves (1930) presented an early summary of caves and shelters in the region. While much of the published work for this period is strictly descriptive, those which do undertake any classificatory or synthetic statements seem to rely on the culture history scheme developed by Kidder (1927; 1962) for the northern Southwest.

C. B. and Harriet Cosgrove conducted some of the earliest professional work in the region, during 1928, in the southern Hueco Mountains. Working in a series of caves currently located on Fort Bliss, the Cosgrove excavations and collections resulted in a variety of "Puebloan" and "Basket-maker" artifacts, including a large number of sandals, several atlatls, burials, and basketry. While a manuscript of this work was completed in 1934, it was not published until 1947. Cosgrove (1947) classified the wide array of artifactual material recovered from these excavations using the cultural history scheme developed by Kidder (1962). Special attention was focused on the "Basket-maker" artifacts. In conjunction with cave and shelter excavation data from the Gila region and the middle Rio Grande, Cosgrove (1947:164-170) compared the Hueco cave materials with those from the San Juan. He concluded that the Hueco and Upper-Gila material should be classified as similar, and that this material reflected the "Hueco Basket-maker" people. Cosgrove (1947:170) further concluded that "...the Hueco Basket-makers were an off-shoot of the San Juan Basket-maker, that...spread southeast along the Rio Grande into western Texas and perhaps into Coahuila, Mexico..."

With the exception of Cosgrove's work, and a cursory survey of the region by Sayles (1935), the pre-1940s excavations and surveys were primarily concerned with the Pueblo period. For example, Bradfield (1929) and Stubbs (1930) report on pueblo excavations conducted around Alamogordo,

information that was subsequently reported by Lehmer (1948). Both Bradfield (1929:5-6) and Stubbs (1930) make reference to the artifactual remains present at these sites as reflecting cultural influence from outside the region, primarily based on ceramics from better studied regions.

In addition to these early excavations, Mera (1931, 1938, 1943), Stallings (1931) and Mera and Stallings (1931), provided early summaries of ceramics types in the region, and Alves (1930, 1932a, 1932b, 1934) provides early accounts of material culture, again primarily associated with Pueblo occupations in the region. Stallings (1932) provides a brief overview of the region's ceramics and limited information on several known sites, concluding that the artifacts in the region reflected a "pueblo" occupation. Finally, Herbert Yeo provided descriptions of sites along the Rio Grande, including observations in Sierra and Doña Ana counties, which are on file at the Laboratory of Anthropology in Santa Fe.

The pre-1940 period, then, focused primarily on the Pueblo period. This was probably related to the higher visibility of such sites, their large size, and their location along the fans and river that were undergoing modern development. The presence of painted ceramics of both local and extra-local origin, along with a high frequency of shell beads and stone "fetishes," also contributed to this pueblo focus. As the work of the Cosgroves had not yet appeared in print, there was essentially no syntheses of prepuebloan archeology in the region. The pueblo focus had resulted in descriptions of artifacts and architecture, which were primarily explained by reference to interaction with surrounding areas. Information on ceramics was of special concern, as ceramics, especially those that were "intrusive," provided both chronological data and ways to trace cultural interaction, a position consistent with the culture history focus. This focus was to dominate the region until the early 1970s.

3.3 INITIAL SYNTHESIS AND SUPPORTING WORK

Lehmer (1948) provided the first truly synthetic framework for the region. Working essentially under the same theoretical position as early researchers, but with a "Mogollon" (Haury 1936) rather than "Anasazi" (Kidder 1962) focus, Lehmer conducted a series of excavations throughout the region in 1940. Lehmer's excavations essentially focused on three sites. In conjunction with previous survey and excavations, he conducted work at the Los Tules site, a large pithouse site located along the Rio Grande, La Cueva, a cave located in the Organ Mountains, and the Bradfield site, a pueblo located in the Tularosa Basin near the Organ Mountains. He also relied on the earlier work of Stubbs (1930) and Bradfield (1929) at pueblo sites near Alamogordo. These excavations and observations in the region provided the first detailed synthesis of the prehistory of the region. Lehmer (1948:70-90) used these data to define the Jornada Branch of the Mogollon people (see Haury 1936).

Lehmer's excavations at Los Tules represents the first systematic research into the Pithouse period. Los Tules is, in effect, the type site for the Mesilla phase. Lehmer excavated 11 pithouses at the site. In light of subsequent excavations in the region, these structures are somewhat anomalous, being both quite large and deep. Several additional features, including two internal storage pits and two external, bell-shaped pits of substantial size, were located at the site. Over 5,600 ceramics were collected from Los Tules, and "intrusive" wares accounted for roughly 14 percent of this total. The intrusives were exclusively from the Gila/Mimbres area, and included Mimbres Black-on-white, Mimbres Corrugated, San Francisco Red, and Alma Plain.

Work at La Cueva provided stratigraphic evidence that allowed the elucidation of ceramic change through time. Excavating primarily on the talus of the "hideously disturbed" cave (Lehmer 1948:35), Lehmer's excavations apparently produced few artifacts, but did uncover El Paso Polychrome

ceramics, El Paso Brown, Chupadero Black-on-white, Mimbres Black-on-white, and Three Rivers Red-on-terracotta. It appears that intrusive ceramics were confined to the upper 30 cm of the deposits and El Paso Polychrome was confined to the upper 60 cm. Below 60 cm, only El Paso Brown ceramics were recovered (Lehmer 1948:38).

The final site investigated by Lehmer was the Bradfield site. In conjunction with the previous work of Stubbs and Bradfield at the Alamogordo sites, it allowed the elucidation of the El Paso phase. The Bradfield Site consisted of 16 rooms, 13 of which were excavated. Over 94% of the ceramics recovered were El Paso Polychrome, with Chupadero Black-on-white, Three Rivers Red-on-terracotta, Gila Polychrome, and Ramos Polychrome being the primary intrusive wares (Lehmer 1948:47). Lehmer reports on a similar range of ceramic types from the Alamogordo sites; the principal difference is an increased occurrence of Lincoln Black-on-white in these northern sites (1948:59).

Lehmer's synthesis resulted in the establishment of a basic phase sequence, with phases serving as time and space boundaries for cultures in the area. Employing the dendritic model of Gladwin (1934, 1936; Gladwin and Gladwin 1934; see also Haury 1936), he identified the region as the "Jornada Branch of the Mogollon Culture." His primary spatial boundary was between the northern and southern regions, the latter of which includes the El Paso area.

In the southern region, Lehmer identified four phases. The earliest was the Hueco phase, which predated A.D. 900. It was described as a "manifestation of the Cochise pattern," a pattern seen as the "concrete expression of the Mogollon Root" (Lehmer 1948:90). While none of Lehmer's excavations dealt with this phase, he relied on early work of Sayles (1935), Cosgrove's yet unpublished work, and conversations with local amateurs to provide a brief description of common artifacts and a discussion of the distribution of similar "Cochise" artifacts from the surrounding regions.

The Hueco phase was followed by the Mesilla phase. Defined based on his excavations at Los Tules, La Cueva, and surface collections on sites in the region, Lehmer argued that the phase consisted of circular and rectangular pithouses, El Paso Brown ceramics, and occasional Mimbres Black-on-white. While infrequent, several cases of painting on the local ceramics were uncovered. Lehmer argued that the Mesilla phase arose from the Hueco phase as a result of interaction with surrounding cultures, primarily the San Marcial phase to the north, and to a lesser extent, the San Francisco and Three-circle phases in the Gila area (Lehmer 1948:77). Groundstone assemblages were dominated by basin metates and one-hand manos. Based on the occurrence of Mimbres Black-on-white, and the lack of later ceramic wares, Lehmer suggests a time range of between A.D. 900 and 1100 for this phase.

Lehmer defined a third phase primarily on his work at La Cueva and surface collections of sites in the region (Lehmer 1948:78-80). He suggests that the upper deposits of this cave, which contained aspects of both the preceding Mesilla phase and the later El Paso phase, reflected a "Doña Ana phase" occupation. The application of paint to the El Paso Brown ceramics increased, and Lehmer suggests rim form changes on vessels relative to earlier and later phases, a suggestion subsequently explored by West (1982) and Whalen (1993). Though no formal excavations of open sites had been conducted, Lehmer suggested that the architecture consisted of both adobe surface structures and pithouses. Intrusive ceramics, including the occurrence of both Mimbres Black-on-white and Chupadero Black-on-white, were used to assign a date range for the phase at between A.D. 1100 and 1200.

Lehmer's final phase, El Paso, was the best known, having received the most attention both by Lehmer and earlier researchers. Defined by the occurrence of El Paso Polychrome and contiguous adobe surface rooms, the phase was argued to reflect the supreme prehistoric development in the cultural sequence. Basin metates and one-hand manos were less common than in previous phases,

having been increasingly replaced by slab and trough metates and larger manos. Interestingly, the pottery seems to represent a complete replacement of El Paso Brownware. That is, there is no undecorated pottery during this phase. The principal intrusives include Chupadero Black-on-white, Gila Polychrome, and wares from Chihuahuan (e.g., Ramos Polychrome). Based on the intrusive ceramics, Lehmer suggested a time frame of A.D. 1200 to 1400.

Following Lehmer's synthesis, and the publication of Cosgroves work on the "Hueco Basketmakers," little professional work was published in the region between 1948 and the late 1960s. Moore (1947) published a description of 12-room house ruin and a small Pueblo site located on Fort Bliss, along with a description of a cache of local and regional vessels (Moore and Wheat 1951) recovered from northeast El Paso. The local amateur society, EPAS, became increasingly active in the late 1960s and throughout the 1970s. The journal of the society, *The Artifact*, provided an important outlet for both amateur and professional investigation in the region, a role that it still fills. Much of the work conducted by EPAS during this time period was conducted on Pueblo-period occupations. These El Paso phase excavations included work at the Sargent Doyle Site, the McGregor Site, Condon Field, Escondido Pueblo, Three-Lakes Pueblo, and Hot Wells Pueblo.

While many of these excavations revealed small (fewer than about 15 rooms) pueblos, work at the large site of Hot Wells, located on Fort Bliss near the Texas/New Mexico border, revealed over 100 rooms. While the site had a long history of excavation, work by EPAS (e.g., Brook 1966b, 1970, 1971, 1980) revealed several rooms with evidence that suggest a variety of special functions. In addition, a reservoir was uncovered that may have supplied water to the site's inhabitants (see Brook 1966b; Scarborough 1986).

In addition to the Pueblo focus, Paleoindian occupations of the area were also increasingly investigated, primarily by EPAS members (Quimby and Brook 1967; Russell 1968). Of special

concern is the Three Buttes locality, located on McGregor Range. Krone (1975) provides details on collections from this locality; over 140 Folsom points, 26 preforms, and several channel flakes have been collected from this location (Amick 1994:102).

In spite of the fact that Lehmer's work was limited in scope and conducted in the 1940s, his chronological framework and phase-based perspective still dominates much of the region and outlined phase markers in use today. Phases were defined by the development of new artifact types and provided a critical component of interpretation. Phases, periods of temporal stability in a group of artifact types across space, form a critical element by linking the spatial distributions of artifact types with the interpretation of those distributions. Artifact types represented a core idea about the form of an artifact. These forms changed as a result of the development, borrowing, or wholesale replacement of that basic core idea. Changes, observed by the introduction of new artifact types, served as both the definition of a new phase and as an explanation for why the new phase developed. For example, Lehmer (1948:78) explains the development of the Doña Ana phase from the Mesilla phase, a transition defined on the basis of the development of local painted ceramics at La Cueva, as resulting from "...contact with Anasazi groups to the north..." along with borrowing from the "Mimbres people already in the area" (Lehmer 1948:78). Few researchers would currently argue that contact with surrounding groups necessarily explains artifactual change. As will be suggested below, the explanatory focus has, within the last few decades, shifted to a focus on ecological/environmental concerns. Yet, we continue to group artifacts and sites into phases that are defined by traditional cultural history markers.

3.4 DATA ACQUISITION AND SYSTEMATICS

By the late 1960s, then, it was still the case that the majority of work was concentrated on the highly visible Pueblo Period occupations, or the

Paleoindian (primarily Folsom) finds in the region. Knowledge of the pithouse period had changed little from Lehmer's original 1940s work, and knowledge regarding the Archaic was essentially limited to Cosgrove's early excavations. As late as the mid-1970s, researchers still relied on Lehmer's cultural history scheme to identify stylistic markers, and assigned sites to phases based on similarities in artifact types. The chronology for both the close of the Archaic period and all of the Formative was consistent with Lehmer's suggestions. However, the focus on the ends of the prehistoric continuum, the acceptance of Lehmer's basic chronology, and the focus on cultural interaction as causal, all were about to change.

These changes in the post-1960s archeology work in the area were the result of two principal factors. First, primarily as a result of mandated Cultural Resource Management work in the region, a large survey and excavation database was generated and, second, changes in the explanatory focus, which were occurring in archeology in general, began to filter into the lowland Jornada region. The results of these two factors were:

- (1) the identification of a substantial number of sites in nonriverine settings;
- (2) the realization that the vast majority of sites lacked any temporally diagnostic artifacts;
- (3) the documentation of a significant Archaic occupation in the region;
- (4) the clarification of a substantial pithouse or Mesilla phase component in the region; and
- (5) the redefinition of the chronology as a result of the increasing use of absolute dates.

Accompanying this explosion in data was an increasing emphasis on environmental/ecological/adaptive explanations for changes in the record, but the data were still grouped in terms of the cultural history time blocks established by Lehmer.

Human Systems Research (HSR) was one of the first groups to introduce a "systemic" perspective into the region. Though much of their work has been conducted in the northern portion of the Tularosa Valley and in the Sacramentos, HSR's Technical Manual (1973) and its report on a survey of the Three Rivers Drainage (Wimberly and Rogers 1977) were explicit calls for a "...systems theoretical approach to explain the adaptation of extant human populations to their environment..." (HSR 1973:16). That is, HSR was one of the first groups to incorporate changes in the discipline, initiated in the early 1960s, into the local area.

This concern with adaptation was increasingly incorporated into local professional and amateur projects in the region, including a number of small early CRM projects conducted in the El Paso area during the 1970s. These included projects located on the eastern slopes of the Franklin alluvial fans (e.g., Aten 1972; O'Laughlin and Geiser 1973; Hard 1983b; O'Laughlin 1979; Thompson and Beckett 1979). However, a series of survey projects located on Fort Bliss and conducted by Whalen (1977, 1978) and Carmichael (1986a) were to substantially change the way that archeology was conducted in the lowland area. The results of these surveys revealed a substantial number of small sites, many of which lacked any temporally diagnostic artifact types that were essential for placing occupations into cultural history periods (see also Beckes et al. 1977; Skelton et al., 1981). Nevertheless, synchronic models of adaptation were still employed to account for these distributions, even though over 85% of the sites identified by survey lacked any diagnostic artifacts.

3.4.1 Synchronic Models

The dominant systematics operating at present considers sites within phases. Whereas under the traditional cultural history position in which sites were seen as locations that contained artifact types that reflected similarity in culture, sites are now seen as locations of past behavior that reflected differences in adaptations to environmental and economic conditions. As in the pre-1945 period, phases are viewed as periods of stability. Changes

between phases, previously explained in terms of new influences or actual migrations of people that produced a new cultural matrix, are now explained by reference to economic and environmental relationships. Increasingly, phases are seen as simply temporal blocks. Site distributions within phases, as well as changes between phases, are explained by reference to adaptation to environmental concerns rather than attributed exclusively to "cultural" concerns. Yet, these phases are still frequently defined by reference to changes in artifacts that were originally thought to identify the introduction of new cultural influences.

A variety of projects fall under the synchronic umbrella. These include those discussed previously conducted by Whalen (1977, 1978, 1980, 1985, 1986, 1993, 1994) and Hard (1983a) for the Mesilla phase, the work of Anderson (1993) and MacNeish (1993) for the Archaic period, and the work of Mauldin (1986) for the El Paso phase. Using temporally diagnostic artifacts to place sites into periods, site distributions are considered against environmental variables. Ethnographic models are then consulted, and the adaptation during a given period of time is reconstructed. These synchronic models are then stacked in time, differences between the models exposed, and diachronic explanations provided for these differences. The primary explanation for change involved some form of population growth resulting in subsistence and settlement changes.

While these synchronic/diachronic models provide a useful synthesis of phases, most sites lacked any diagnostic artifacts. Currently, for example, the Fort Bliss site files contains data on nearly 14,000 prehistoric sites, 86% of which lacked any diagnostic artifacts. Thus, without the availability of absolute chronometric dates, these synchronic models account for only a small percentage of the known record. The failure of synchronic models to effectively integrate the vast majority of the record led several researchers to propose alternative systematics for describing and explaining the record.

3.4.2 Fluctuating/Competing Adaptations

The focus on large sites to the exclusion of the more numerous smaller occupations necessarily characteristic of synchronic models has led several researchers to question both the utility and reliability of this phase-based synchronic sequence. A variety of researchers have suggested alternative schemes, ones in which either distinctive adaptive trajectories are represented, or ones in which a fluctuation between a dependence on wild foods and a dependence on farming occurs (see Kauffman and Batcho 1983, 1988; Upham 1984; Carmichael 1983, 1985; Stuart and Gauthier 1984; Johnson and Upham 1988). Following Cordell and Plog (1979), these researchers argue that the linear models of adaptation, such as those inherent in the phased-based perspective, obscured cultural variation by focusing on modal characteristics and emphasized within-phase continuity as opposed to periods of change. The nondiagnostic sites are seen as evidence for that cultural variation. Alternative schemes were eventually suggested in which the archeological record was argued to reflect either distinctive adaptive systems or economic fluctuation between a dependence on wild foods and a dependence on farming.

Relying on terminology developed to describe ecological systems, researchers began to identify "stable" or "power-based" systems that were characterized by large, architectural sites, often with substantial dependence on agriculture and "resilient" or "efficiency" systems characterized by small, nonarchitectural artifact scatters (see Carmichael 1983, 1985; Johnson and Upham 1988; Kauffman and Batcho 1983; Stuart and Gauthier 1984; Upham 1984, 1994). Carmichael (1985a:30) has summarized aspects of this position in noting that "Sites used to define a phase sequence will represent the remains of a stable strategy while the others (perhaps the majority) could be the byproducts of several strategies."

Both the focus on economic fluctuations and the "adaptive diversity" approach involved the suggestion that these small lithic sites represented different hunting and gathering adaptations. In the

fluctuating adaptive position, cultural systems oscillated between an emphasis on agriculture and an emphasis on hunting and gathering. For example, Carmichael (1983, 1986a) argues that the archeological record from the central Jornada indicates a "cyclical pattern" in energy production. In the competing adaptive approach, which is the more frequently relied upon scenario, these small sites are contemporary with the larger sites. As Johnson and Upham (1988:69) note:

In the Jornada Mogollon region, the model of adaptive diversity suggests that sedentary agriculturalists could have settled in the Rio Grande River Valley and in other areas where deep alluvium exists... At the same time, other parts of the environment...could have been utilized by groups relying on a mobile settlement strategy that were largely dependent on hunting and gathering.

Clearly, a variety of adaptations may have been present at various points in the past. The "adaptive diversity" or fluctuating adaptive scenarios recognize this possibility. Unfortunately, there is no methodology for recognizing these distinct systems. Whereas previously differences between sites were "explained" by reference to the different cultures that produced them, or by differences in adaptation to different environmental conditions, those sites that do not fit into the traditional phase system are now "explained" by creating a new category of "adaptation" that is not required to conform to the traditional phases.

3.4.3 Nonsite and Landscape Issues

Finally, a number of nonsite or landscape approaches have been attempted in the region as well (see Camilli et al. 1988; Camilli and Ebert 1992; Seaman et al. 1988). Perhaps the most productive example in the local area is that of Camilli (1988; see also Camilli et al. 1988). Using point provenience artifact data from a series of 400 x 400 m blocks along the west mesa region northwest of El Paso, Camilli demonstrates that a variety of different clusters can be isolated

depending on the scale of analysis. She correctly concludes that "varying archaeological densities within a region are likely the result of different histories of debris accumulation" rather than any single "function" (1988:61). In contrast to a site-based analysis, Camilli (1988) analyzes these distributions by grouping them into "clusters" using a cluster algorithm, and investigates patterns in artifact variety and number as a function of "occupational history" (see also Camilli and Ebert 1992) rather than as a distinct settlement type.

Camilli's analysis, as well as that of others who take a "nonsite" approach, clearly recognizes important problems with the site concept. Yet, the interpretations of the archeological patterns, either in terms of past systemic, behavioral, or nonbehavioral processes, remain problematic. The nonsite approach clearly allows the identification of different patterns, but the proponents of this approach still do not have any systematic way to interpret those patterns.

Recently, several researchers have echoed the arguments of the "nonsite" advocates that interpreting sites as directly informative of discrete past activities may be unwise (see Doleman et al. 1991; Swift and Doleman 1991; Leach et al., 1994; Mauldin and Leach 1994a; Mauldin 1995). Relying on recently completed geomorphic mapping of Fort Bliss by Monger (1993a), as well as studies of the impact of survey transect spacing on site size, Mauldin (1994, 1995) argues that many of the variables commonly used to classify sites (e.g., artifact variety, artifact density, the presence of temporally diagnostic artifacts) into different site types (e.g., Fresno phase macrobands, Mesilla phase residential sites) are, in part, a function of geomorphology and survey intensity. This topic is discussed further in Chapter 11.0.

Especially in eolian contexts, the size of any archeological site is a function not only of prehistoric cultural behavior but also of patterns of erosion and deposition. Larger sites, as a function of incorporating more area, generally have more artifacts, a greater variety of artifacts, and a larger

number of temporally diagnostic artifacts. Conversely, smaller sites often have fewer artifacts, fewer artifact types, and generally lack temporally "diagnostic" artifacts (see Leonard and Jones, 1989). To the degree that site boundaries and site size are etic constructs - our attempts at pattern recognition - our synthetic interpretations of the archeological record may be due as much to geomorphological and/or methodological biases as to past culture and behavior. While the site concept is a useful and valid management tool, the use of sites as directly representative of past behaviors is greatly complicated.

Working from this "landscape" approach, Mauldin (1995; see also Mauldin, Leach, and Monger 1994) uses radiocarbon and obsidian hydration dates, groundstone data from throughout the region, and paleoenvironmental data to argue that a significant reorganization of mobility and subsistence occurred in the local sequence between A.D. 700 and 1000. This shift, which may have involved a change in the way that the central portion of the Hueco Bolson was used, along with a shift in the importance of agriculture in the subsistence base, is not associated with a shift in artifact types traditionally used to isolate phase sequences. While additional research, especially on reconstructing paleoenvironmental conditions is required, this research clearly suggests that an exclusive focus on phase and site-based systematics may obscure significant adaptive change in the local archeological sequence.

3.5 SUMMARY

The history of research in the El Paso area, then, reflects a focus on sites with large artifact inventories that include temporally diagnostic types that can be used to place sites into phases. The phase sequences and settlement models discussed above are derived primarily from a few sites, most of which have many artifacts, are large, or are cave/shelter occupations. In addition to a focus on large sites with temporally diagnostic artifacts, note that the phase sequence, which is derived from cultural historical notions regarding the reasons for cultural change, does not necessarily focus on

adaptive shifts. That is, the phase sequence outlined above is necessarily tied to relatively small changes in aspects of material culture that can be observed on survey data. We treat these changes as chronological markers, placing sites and components on sites into temporal blocks. However, these temporal blocks may not be the most efficient for dealing with subsistence shifts, changes in mobility, or major changes in adaptation.

For example, the ongoing debate regarding the Doña Ana phase primarily involves our ability to recognize an early variant of El Paso Polychrome. There is, however, surprisingly little debate regarding the utility of this distinction for adaptive questions. Recent research (e.g., Mauldin 1995), demonstrates a significant change in land use and subsistence not associated with any change in the artifacts traditionally used to define phases. Further, data demonstrating that sites are (in part) a function of geomorphic processes and modern decisions regarding survey intensity and site definition in this environment, suggesting that the continued dependence on cultural history models for describing periods of stability and change may be unwarranted.

PART II: RESEARCH DOMAINS

4.0 CHRONOMETRICS RESEARCH DOMAIN

James T. Abbott and Raymond Mauldin

Of all the types of information potentially obtainable from archeological sites on Fort Bliss, chronometric information is probably the most crucial because it provides the information necessary to place each site within a temporal context, and thus facilitate intersite analyses. Almost every type of meaningful analysis, from investigations of intrasite patterning to examinations of regional settlement and subsistence systems, require identification and isolation of penecontemporaneous components. At present, the percentage of identified sites with any temporal assignment on Fort Bliss is extremely low, and even many of these are tentatively identified with a particular timespan on the basis of only one or two diagnostic artifacts that may not be representative of the occupations that formed the site. As a result, investigations of technological change, subsistence, settlement patterning, and cultural interaction are seriously hampered. It can therefore be argued that no significant progress in unraveling the cultural record can be made without accompanying progress in dating the constituent components. The fact that the sites on Fort Bliss have proven very difficult to date requires a renewed and focused resolve to use a wide range of resources for dating, including the exploitation of innovative techniques.

A number of dating techniques have been, and continue to be, developed for application in the Quaternary sciences, and many of these techniques have great potential utility for archeology. Table 7 provides a list of these methods, which vary considerably in applicability and precision. Six different classes of methods are identified. Sidereal methods are the most accurate, in that they allow unambiguous assignment of a calendar age. Isotopic methods measure changes in material composition due to radioactive decay or changes in isotopic composition due to cosmic ray bombardment, while radiogenic methods measure cumulative nonisotopic effects of isotopic decay, such as electron trapping or crystal damage. Both

of these groups of methods also provide a numerical age, but one that is based on a statistical expression of probability and that typically has an associated error estimate. Chemical and biological methods measure the results of time-dependent chemical or biological processes, while geomorphic methods address the cumulative effects of complex, interrelated physical, chemical, and biological processes on elements of the landscape. Finally, correlation methods allow for dating by establishing equivalence with dated baselines using time-independent properties.

As noted in Table 7, the result of these methods vary in precision. Typically, dating methods are classified as either chronometric or relative techniques (Michels 1973). Chronometric methods are also frequently termed "absolute" methods, but this term is presently discouraged as hyperbolic and misleading (Colman et al. 1987). Chronometrics provide a numerical age (with or without an error factor), while relative methods provide a nonscalar indication of age relative to a point of reference (e.g., *A* is older than or younger than *B*). Taking this classification one step farther, Colman et al. (1987) identifies four levels of precision in results: numerical age, calibrated age, relative age, and correlated age. In this scheme, numerical and calibrated ages are equivalent to the chronometric techniques, but differ in that calibrated ages are dependent on calibration with independent methods to minimize the effects of external environmental variables, while numerical methods are not. Correlated ages are those that use nontemporally dependent attributes to obtain an age estimate. The connotation of relative methods is unchanged; it describes methods that provide an ordinal indication of the age of different entities, with or without a qualitative assessment of the magnitude of difference. Note that most techniques can be applied to achieve several different types of results with differing degrees of precision, depending on the depth of information and the aggressiveness of the interpretation.

Table 7 Quaternary Dating Methods.

| TYPE OF RESULT | | | | | |
|--------------------|------------------------------------|-----------------------------------|-------------------------------|------------------------------------|--------------------|
| NUMERICAL AGE | | CALIBRATED AGE | | RELATIVE AGE | |
| | | | | CORRELATED AGE | |
| TYPE OF METHOD | | | | | |
| Sidereal | Isotopic | Radiogenic | Chemical and Biological | Geomorphic | Correlation |
| Historical Records | Radiocarbon (conventional and AMS) | Fission Track | _____ | Soil Profile Development | Lithostratigraphy |
| Dendrochronology | Potassium-Argon | _____ | Amino Acid Racemization | Rock and Mineral Weathering | Tephrochronology |
| Varve Chronology | Uranium-Series | Thermoluminescence | Obsidian and Tephra Hydration | Progressive Landscape Modification | Paleomagnetism |
| _____ | _____ | Optically-stimulated Luminescence | Lichenometry | Rate of Deposition | Archeomagnetism |
| | Uranium-trend | Infrared-stimulated Luminescence | Soil Chemistry | Rate of Deformation | Fossils |
| | Cosmogenic Isotopes | Electron-spin Resonance | Rock Varnish Chemistry | Stratigraphic Superposition | Seriated Artifacts |
| | | | Oxidizable Carbon Ratio (OCR) | Geomorphic Position | Stable Isotopes |

Medium gray bars represent most common application, while light gray bars represent less common applications (e.g., exceptionally cautious or bold interpretations). Methods above line in the first four columns routinely produce reliable numerical ages, while methods below line are more experimental and/or involve nonradioactive processes or processes whose effects on age estimates are not well established.

The following discussion outlines problems and prospects of a variety of dating techniques to application on Fort Bliss. While basic descriptions of the fundamental principals underlying each method are presented, readers interested in detailed methodological discussions are referred to general treatments of dating methods (e.g., Rutter 1985; Michels 1973) and to specific references cited in each section.

4.1 CHRONOMETRIC DATING TECHNIQUES

Chronometric dating techniques are methods that yield a numerical age, either directly or through calibration with an independent method. They are equivalent to the numerical and calibrated ages of Colman et al. (1987).

4.1.1 Luminescence Dating

Luminescence dating has existed in principal for many years (Daniels et al. 1953; Kennedy and

Knopf 1960), but has seen only limited application in North America due primarily to expense and time requirements, remaining ambiguities in the method, and a shortage of facilities capable of conducting the analysis. Three different variants of luminescence dating (all of which are based on the same basic principle) are recognized: thermoluminescence (TL); optically stimulated luminescence (OSL); and infrared-stimulated luminescence (IRSL). Good, generalized reviews of the principles and prospects of various aspects of luminescence dating include Dreimanis et al. (1985), Aitken (1985, 1989, 1994), Smith et al. (1990), Wintle and Huntley (1982), and Wintle (1993).

Luminescence dating is based on the fact that irregularities in the crystal lattice of silicate minerals (e.g., quartz, feldspar) can trap stray electrons produced by radioactive decay of radioactive atoms in the material or in the surrounding matrix. Over time, more and more of these electrons are trapped until they are released

by kinetic excitation of the lattice structure, which is caused by the input of electromagnetic energy (i.e., light or heat). This release produces a faint flash of light that is proportional in intensity to the number of electrons released. Captured by a photomultiplier cell, this energy can be used to calculate the length of time that has elapsed since it was last "zeroed" by exposure to the same type of energy, provided that its composition and radiation history are known.

Electron traps within a crystal lattice have different characteristics, which are reflected in the temperature necessary to cause release of the electron. "Shallower" traps are capable of trapping and holding an electron for a short time, and release the electron after low-level stimulation, while "deeper" traps can hold electrons for extremely long periods (millions of years) and release the electrons only after the crystal lattice is increasingly stimulated. In TL dating, this equates to heating to higher temperatures. As a result, heating of a specimen for measurement results in a characteristic "glow curve" when thermoluminescence is plotted against temperature, as increasingly deeply trapped electrons are released. In addition, various minerals have significantly different types of traps due to unique characteristics of each crystal structure.

The age of TL samples is obtained by solving for the equation:

$$\text{age} = \frac{\text{natural TL}}{(\text{TL sensitivity}) \times (\text{annual dose of radiation})}$$

where natural TL is the amount of thermoluminescence given off during the initial heating, TL sensitivity is a measure of the ability of the sample to trap electrons, and annual dose refers to the natural influx of alpha, beta, and gamma particles that the sample was exposed to.

TL sensitivity is relatively easily determined by zeroing the sample, subjecting it to a known dose of radiation, and measuring the amount of trapped TL. Determination of the annual dose is

considerably more difficult. One approach is to determine the content of radioactive elements (uranium, thorium, potassium-40, and rubidium) by a combination of neutron activation and atomic absorption photometry; the contributions of this fraction to the annual dose are calculated from empirically derived tables, while the contribution of cosmic rays is calculated by the thickness of the overburden. Alternatively, direct particle-counting techniques may be employed, or measurements may be made on-site with a sensitive dosimeter or a portable gamma spectrometer. In all cases, this calculation of annual dose is complex and requires assumptions about burial history (which affect the influx of cosmic rays) and long-term soil moisture trends (which are very important due to the sharp attenuation of radioactive particle travel by water) (Aitken 1989).

Thermoluminescence is commonly applied to heated artifacts, such as ceramics and burned chert (Göksu et al. 1974; Kennedy and Knopff 1960; Ichikawa 1965; Valladas 1978). In fact, much of the time available in TL laboratories is given over to "authentication" of antiquities prior to the sale by auction houses, such as Southeby's in London (which, because background information on annual dosimetry is typically lacking, usually amounts to verification that the piece is indeed old, rather than a true estimate of age). Refinements to the technique, such as dating based on zircon crystals (e.g., Sutton and Zimmerman 1976) have some potential, but at present thermoluminescence dating is not as accurate, as rapid, or as easily obtained as radiocarbon dating (Aitken 1989).

Optical and infrared-stimulated luminescence are relatively newer methods (Huntley et al. 1985; Hutt and Jaek 1989) that are currently experiencing intense interest by Quaternary scientists (e.g., Smith et al. 1990; Edwards 1993; Stokes 1992; Wintle et al. 1994). They are very similar in principle to TL, differing primarily in that the initial zeroing and the analytical stimulation is provided by light rather than heat. In OSL dating, a monochromatic green laser (514 nm) is typically used, stimulating emission in the blue-ultraviolet range (approximately 325 to 450 nm). IRSL

involves stimulation in the near-infrared (approximately 800 to 1,000 nm), and emits in the visible and ultraviolet range (approximately 300-700 nm). IRSL is not applicable to quartz (which has no response to IR stimulation) and has currently been applied only to feldspars. It has the advantage of being relatively simple to determine, however, and is amenable to automation (Aitken 1994).

The characteristics of traps in optical methods is treated somewhat differently, as optical stimulation does not evacuate thermal traps, and there is no good method for differentiating between shallow and deep traps (Aitken 1994). Typically, samples are preheated to evacuate traps with poor stability before measurement (Wintle 1993; Aitken 1994). Age is then calculated by the equation:

$$\text{Age (a)} = \frac{\text{Equivalent dose (Gy)}}{\text{Dose rate (Gy a}^{-1}\text{)}}$$

The advantage of OSL and IRSL is that initial zeroing can be accomplished by sunlight, which allows for the dating of sediments. Most applications to this point have been directed at eolian sediments (e.g., Stokes 1992; Wintle 1993; Edwards 1993; Clarke 1994), which are best exposed to sunlight and thus zeroed most completely, but optical dating of alluvial, lacustrine, and colluvial sediments is also theoretically possible (Aitken 1994) and has been demonstrated to a limited extent (Fuller et al. 1994; Clarke 1994).

At present, luminescence dating holds considerable promise, but is in a constant state of refinement and must still be considered experimental because so many aspects remain poorly understood. As Aitken (1989) notes, these complications have thus far dashed early archeological hopes of a cheap, rapid substitute for radiocarbon dating. However, luminescence dating can provide a valuable compliment to radiocarbon, and is applicable to many situations where carbon dating is impossible. In particular, the potential for dating of eolian sediments has tremendous implications for

elucidation of the archeological and paleoenvironmental histories of the Fort Bliss region. Moreover, recent advances in methods (e.g., IRSL, automation, single-aliquot measures) and the re-establishment of a luminescence dating facility in North America (at the Desert Research Institute, University of Nevada Reno) have the potential to greatly facilitate cheaper, more frequent application of the method to the wide range of applicable problems.

4.1.2 Electron-spin Resonance Dating

Electron-spin resonance dating is a fairly new (or actually, newly revived) technique that has the potential to date crystalline substances (e.g., carbonates, silicates) over an extremely wide span of time. Like luminescence dating, ESR is based on the measurement of progressive effects of radiation on crystalline substances; namely, the number of unpaired electrons formed by ionizing radiation and trapped in crystal lattice defects. While luminescence measures the extent of trapping by freeing the electrons from the traps, ESR measures absorption of microwave energy by the electrons trapped in the sample, which is proportional to the number of unpaired electrons trapped in the crystalline structure. Because the electrons are not liberated from the traps in the process, ESR is a nondestructive technique that can be performed repeatedly on the same sample (Ikeya 1985).

Once the total radiation dose represented by those trapped electrons is known, calculation of age is performed in the same manner as in luminescence dating:

$$\text{ESR age (T)} = \frac{\text{Total Radiation Dose (Gy)}}{\text{Average Annual Dose (D(mGy / y))}}$$

Unlike luminescence dating, ESR can be applied to a wide range of crystalline materials, including shell, bone, speleothems, and soil carbonates, as well as heated siliceous artifacts (Skinner and Shawl 1994; Chen et al. 1994; Grün et al. 1988; Özer et al. 1989; Garrison et al. 1981; Ikeya and Miki 1980; Walther and Zilles 1994).

Unfortunately, each of these applications carries with it some degree of complication, not all of which have been overcome (Aitken 1994). The suitability of individual samples must also be carefully assessed, because inclusions in the structure can create so many traps that the signals are unusable for dating (Chen et al. 1994).

Upper and lower age limits on the technique are imposed by the stability and number of electron traps on the one hand, and detector sensitivity on the other. Maximum ages therefore vary with material, but are often in excess of 1 Ma, while minimum ages of less than 0.5 ka can theoretically be obtained, but only with highly sensitive equipment.

Like luminescence, ESR has considerable potential as a dating method, but has yet to be fully developed. However, research to refine and expand the method is very active, and many areas of potential utility are present on Fort Bliss.

4.1.3 Uranium Series Disequilibrium Dating

Uranium series dating involves the decay of radioactive uranium isotopes (e.g., U^{238} and U^{235}) to lead. This decay progresses through a variety of stages, each with a specific half-life, or time period necessary for half of the atoms to decay to a daughter product (Figure 12). At Quaternary time scales, uranium-series dating focuses on intermediate nuclides with relatively short half-lives. However, because equilibrium develops over long time scales (e.g., the sequence of decay creates new atoms of the intermediate nuclides as older atoms of the intermediate nuclides decay), some factor is necessary to disrupt the system and selectively remove some of the decay products. Uranium series dating is possible because different nuclides have strongly different solubility characteristics. For example, uranium is highly soluble, where other nuclides such as thorium and protactinium are highly insoluble. Thus, water tends to fractionate the nuclides; marine organisms and terrestrial precipitates, such as speleothems and travertine, are initially uranium-rich and thorium-free because the water would have contained only

uranium, while ocean-bottom sediments are initially thorium-rich, because the thorium created through decay precipitates and settles as quickly as it forms. Comparison of the ratios to yield an age is then possible, because one element can be assumed to have been absent (which is not strictly true in some cases). Methods can either measure the loss of parent nuclides or the gain of daughter nuclides. Commonly used uranium-series dating ratios include $^{230}Th/^{234}U$, $^{231}Pa/^{235}U$, $^{234}U/^{238}U$ (Bradley 1985; Lowe and Walker 1984; Schwarcz and Blackwell 1985).

Although uranium-series methods have been used to date fossil carbonates (e.g., Ku and Liang 1984; Ku et al. 1979), the very long half-lives of the radionuclides of interest generally preclude application to archeological problems in North America (the same is true of other common radiometric methods, such as potassium-argon and argon-argon dating, which are not discussed here). At the opposite end of the decay chain, $^{210}Pb/^{206}Pb$ dating can provide age control for very young sediments (<0.2 ka) (e.g., Popp et al. 1988); unfortunately, this too is of little use to most archeological problems.

4.1.4 Radiocarbon Dating

Radiocarbon age determinations are the most common method of obtaining numerical ages used in archeology. They are based on determinations of the ratio between ^{12}C and ^{14}C atoms in the substance being dated. Like uranium-series dating, radiocarbon dating is possible because ^{14}C is radioactive, and decays to ^{12}C with time. Radiocarbon dating is applicable to a wide range of organic and inorganic substances, including wood, charcoal, seeds, leaves, resin, lichen, peat, humus, bone, ivory, tissue, horn, hair, shell, secondary carbonate, soil, sediment, groundwater, and ice. Other substances that have been dated with limited or debatable success include mortar, iron, potsherds, and rock varnish (Geyh and Schleicher 1990).

Radiocarbon is produced in the upper atmosphere by bombardment of nitrogen by cosmic rays,

where it quickly oxidizes to $^{14}\text{CO}_2$, and enters the carbon cycle in the biosphere. Thus, living organisms are in equilibrium with the atmospheric ^{14}C , but once they die, the material begins to decay to ^{12}C . The half-life of ^{14}C is 5730 ± 40 years, but by convention a half-life of 5,568 years originally determined by Libby (1955) is used for most dating to provide comparability between measurements (this is not true in most geophysical applications, which typically base calculations on the correct half-life). As a result, ages on materials older than approximately 40,000 years (roughly eight half-lives) are impractical, because the frequency of individual radioactive decay events declines so steeply that they become impossible to separate from the natural background in counting (Lowe and Walker 1994). By convention, radiocarbon ages are reported in years before 1950, which is abbreviated as years BP or simply BP.

Several factors are involved in the interpretation and correction of radiocarbon ages. First, organisms tend to incorporate ^{14}C and ^{12}C differently, depending on the characteristics of their metabolic pathways, and physical and chemical fractionation can also occur due to slight differences in the properties of ^{14}C and ^{12}C . These fractionation effects can be compensated for by examination of the ratio between ^{12}C and ^{13}C , which is also a stable isotope and occurs in the carbon reservoir in an amount proportional to the amount of ^{14}C . Because the fractionation effect on ^{14}C is roughly double the fractionation of ^{13}C , this ratio can be used to correct for fractionation of ^{14}C in the calculation of age. Such ages are referred to as $\delta^{13}\text{C}$ corrected ages, or simply corrected ages (Geyh and Schleicher 1990; Bradley 1985).

In addition, while one of the basic assumptions of the radiocarbon method is that the reservoir of atmospheric ^{14}C has been constant, this now clearly seems not to be the case. Rather, the amount of atmospheric ^{14}C clearly appears to have varied through time as a result of changes in cosmic ray influx, with the result that ages before 2000 BP are clearly too old (by up to 1 ka by 6000 BP). However, correction of this effect is possible

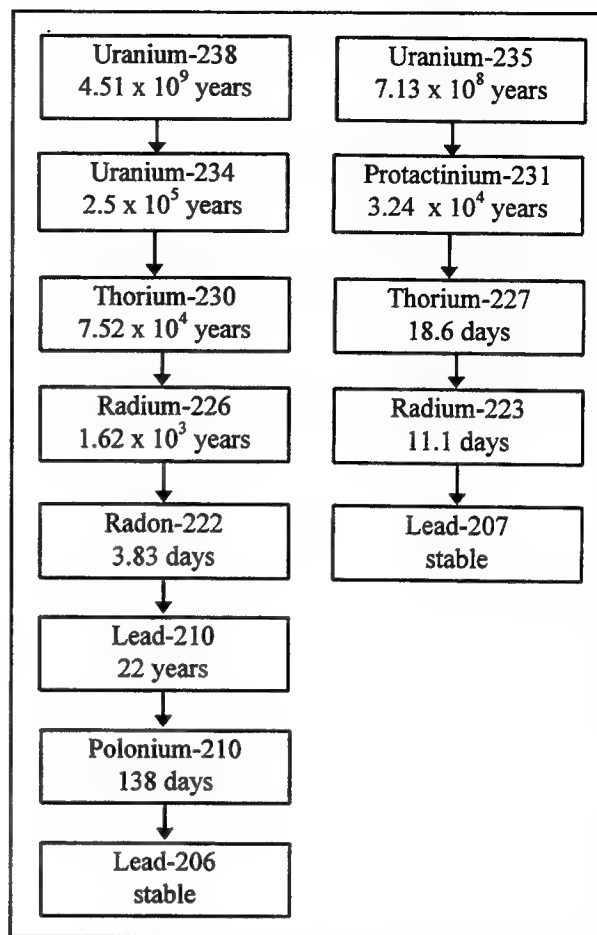


Figure 12 Simplified Decay-series of Uranium-235 and Uranium-238.

through calibration of the age against a continuous, independently derived record that is based on sidereal data like tree rings (Bradley 1985). A variety of calibration datasets with differing time-depths and degrees of precision exist (Stuiver and Reimer 1993), but calibration is generally not possible with samples older than 18 ka and less accurate with samples greater than 7 to 8 ka. After calibration, ages are reported on the sidereal (AD/BC) scale and referred to as "calibrated ages."

More problematic are variations in atmospheric ^{14}C caused by the burning of fossil fuels in recent centuries (the Suess Effect) and by creation of atmospheric ^{14}C by thermonuclear airbursts since 1945 (the Atomic Bomb effect) (Bradley 1985). While the Suess Effect typically results in large error estimates for young samples (typically less

than 400 years), samples that include ^{14}C created by nuclear detonations (e.g., since 1945) typically yield ultramodern ages.

Another important concept to bear in mind is that radiocarbon ages, like all other radiometric techniques, are probability statements. Each radiocarbon age includes not only a numerical age, but also an expression of error, which is a function of a variety of physical factors (e.g., background radiation, self-absorption of beta particles, and statistical uncertainty in radioactive decay); this error function can be reduced, but not eliminated, by increasing sample size and/or counting time. Given a radiocarbon age of 1000 BP and an error factor of 100 years, there is a 68% probability that the true age lies in the range 900 to 1100 BP, a 95% probability that it lies between 800 and 1200 BP, and a 99% chance that it lies between 700 and 1300 BP. Thus, there is a 1% probability that the true age of a sample dated at 1000 ± 100 BP is either younger than 700 BP or older than 1300 BP.

Traditional radiocarbon dating employs an instrument, such as a gas proportional counter or a liquid scintillation counter, to measure the number of emitted beta particles, and hence the amount of decay activity, in the sample. One of the most important innovations in radiocarbon dating since its inception is the advent of common application of particle accelerator mass spectrometer (AMS) methods during the last decade. This technique is capable of directly counting the number of ^{14}C atoms in a sample, rather than the beta particles emitted by the tiny fraction of total ^{14}C atoms that decays during the counting period. Thus, samples that are many times smaller (micrograms rather than grams) may be effectively dated, and dates can theoretically be extended to 15 to 16 half-lives (i.e., up to approximately 80 to 90 ka).

4.1.4.1 Radiocarbon Dating of Wood, Charcoal, and Other Plant Remains

The classic application of radiocarbon dating in archeology is to date discrete plant remains like wood, seeds, leaves, and (in particular) charcoal created by incomplete combustion of such

materials in fires. While radiocarbon ages are the basis of dating used in the packrat midden studies that provide much of the extant paleoenvironmental information (e.g., Van Devender 1990), unfortunately such materials are seldom preserved in archeological sites on Fort Bliss, which is in large part responsible for the general lack of available chronometric information.

However, the advent of AMS techniques holds considerable promise to improve the ability to date sites with limited amounts of wood or charcoal. While conventional radiocarbon dating requires a minimum of 3 to 4 g of charcoal, AMS ages can be obtained from a few flecks of charcoal or a single seed. Naturally, the likelihood of recovering these minute amounts of plant tissue or charcoal is many times greater than it is for recovering significant masses of datable material.

4.1.4.2 Radiocarbon Dating of Bone and Shell

Bone and shell are also amenable to radiocarbon dating, albeit with some limitations. Dry modern bone is composed of a variety of fractions, including apatite (calcium phosphate), calcite (calcium carbonate), collagen (an organic protein), and fat. Collagen ages are the most reliable, but collagen tends to quickly weather away, particularly in harsh arid environments. Errors are frequently introduced in ages derived from other fractions (e.g., apatite and calcite), because these fractions tend to exchange carbon with the environment, particularly when buried in the presence of soil water or groundwater (Michels 1973). In these cases, the carbon dioxide in the surrounding water may be either younger than the sample (if in rough equilibrium with the atmosphere, as most soil water is) or considerably older than the sample if the water contains "dead" carbon (i.e., carbon so old that all measurable ^{14}C has decayed) dissolved from carbonate rocks. This latter problem, termed the *hard water error*, is even more acute in ages of terrestrial and freshwater shell, because such organisms often incorporate dead carbon into their shells directly from the surrounding environment while living (Bradley 1985). Nevertheless, judiciously applied

and interpreted radiocarbon dating can provide reasonable control on the ages of bone and shell in most cases.

4.1.4.3 Radiocarbon Dating of Soils and Sediments

Radiocarbon determinations on soil and sediment differ fundamentally from assays conducted on materials such as wood, charcoal, bone, and shell in that the material assayed represents an amalgam of a large number of different organic sources of many different possible ages, rather than the remains of a single organism or a few discrete, related organisms (Figure 13). Thus, because the exact origin(s) of the organic matter being assayed is essentially unknown, even greater care than usual must be exercised in the selection of samples for dating and in the interpretation of the results.

Organic matter is incorporated and maintained in soils and sediments through a number of different mechanisms, and may take several different forms. The most obvious source of organic enrichment is through the death of animals and plants living on and in the soil, but it may also result from transport of allogenic organic material to a site by fluvial, eolian, lacustrine, or gravity-driven processes. Forms of organic material occurring in soils and sediments include fresh and partly decayed macrofossils, finely-divided solid detritus, and a wealth of chemical decay products, including humic substances, cellulose, lipids, proteins, and carbohydrates. While many of these compounds are subject to further decay and rapid leaching or oxidation, others can be maintained in an active soil for thousands of years (Matthews 1985; Evans 1985). The major problem with radiocarbon dating of soils and sediments in arid environments like Fort Bliss is that the rate of production is so low, and the rate of oxidation so high, that substantial accumulations of organic matter are rare.

The most common mechanisms for holding organic compounds in soils and sediments involve (1) adsorption on various soil components (particularly clays and other colloidal substances) through

physical, hydrogen, and electrostatic bonding and (2) complexing (coordination bonding) with clay minerals or metals. In addition, relatively simple organic compounds may be absorbed into the lattice of expandable clays (Tan 1982; Schnitzer and Khan 1972). Thus, clay-rich sediments and illuvial soil horizons provide an excellent environment for the recovery of humic substances suitable for dating. Organic substances and water typically occupy the same exchange sites on host clays. Adsorption frequently involves substitution of the organic molecule for a water molecule at the bonding site on a clay mineral; washing with water (as in hydraulic transport) can result in reversal of this process and release of the organic molecule (Tan 1982:155).

Although the merits of radiocarbon determinations on soil organics have been widely debated for almost 30 years (e.g., Perrin et al. 1964; Geyh et al. 1971; Scharpenseel 1971; Goh and Molloy 1978; Gilet-Blein et al. 1980; Geyh et al. 1983; Matthews 1985), opinion is still divided on the range of valid applications (Evans 1985; Geyh and Schleicher 1990). However, it is universally recognized that radiocarbon determinations on soil are problematic and must be treated and interpreted with great care. The principle difficulties inherent in soil dating lie in the complexity of organic incorporation and maintenance in the soil system and in the myriad possibilities for contamination of organic matter in soils.

Radiocarbon age determinations on in situ soils measure a suite of organic materials and substances of different individual ages that have accumulated over the "life" of the soil. Each year, new organic matter is introduced as more plants die, decompose, and are incorporated, while leaching and oxidation remove a portion of the highly decomposed fraction. For this reason, radiocarbon ages on soil are commonly termed the *apparent mean residence time* (Campbell et al. 1967; Geyh et al. 1971; Scharpenseel 1971; Matthews 1985). Thus, because the radiometric measure obtained is always intermediate between the oldest and youngest organic matter present, radiocarbon determinations on soil organics only yield a

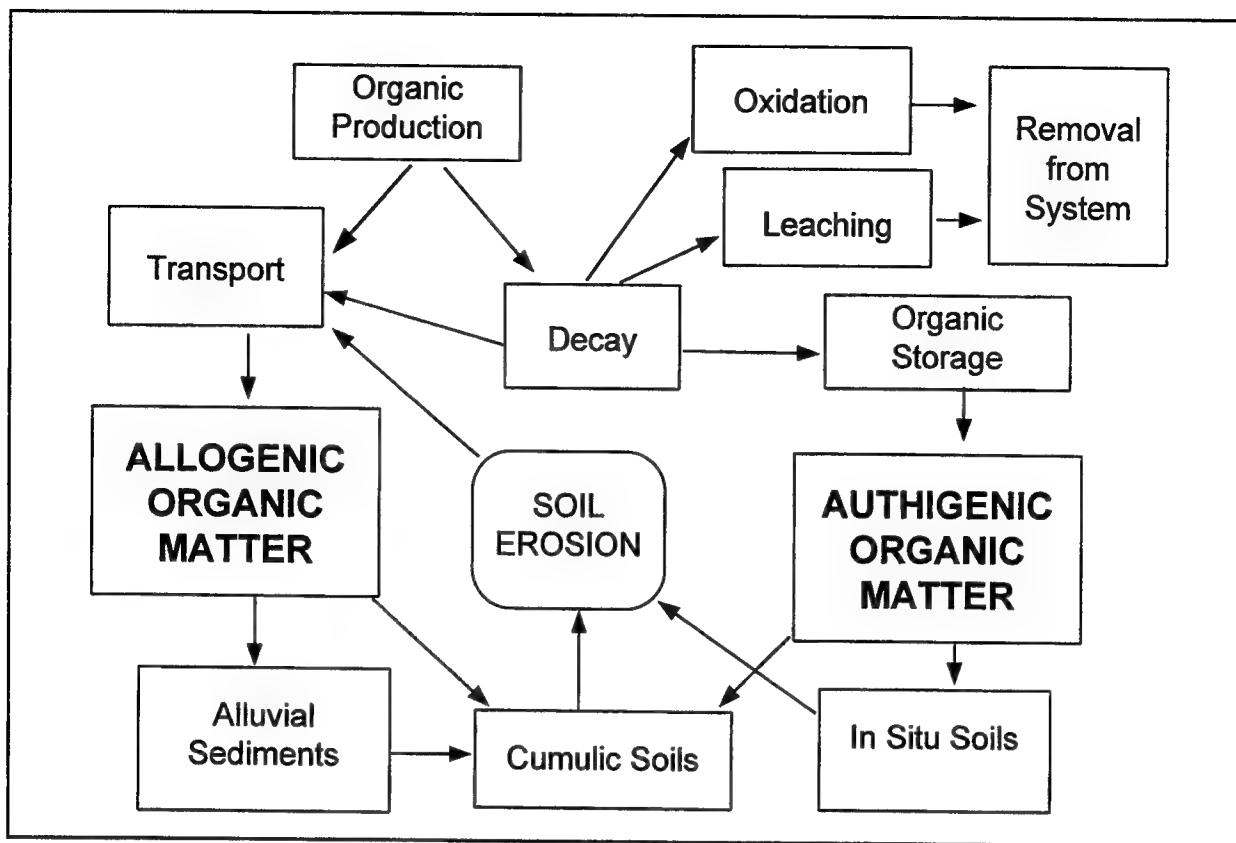


Figure 13 Flow Diagram of Organic Matter Routes Through the Soil/sediment System.

minimum age for the onset of pedogenesis, while determinations on buried paleosols provide only a maximum age for burial. One of the advantages of the Fort Bliss environment is that the high rate of turnover resulting from slow accumulation and rapid destruction of organics implies that mean residence of organics in the soil system is relatively short; unfortunately, it also means that few organics are available for dating.

Four factors further complicating dating of older soils are (1) variations with depth, (2) variation in results between various humus fractions, (3) the achievement of equilibrium conditions in organic content, and (4) contamination by older or younger carbon. A number of investigators (e.g., Scharpenseel 1971; Becker-Heidmann and Scharpenseel 1986) have demonstrated a trend of increasing age with depth in many different types of soil profiles. This effect is believed to be due to a combination of higher organic production near the surface, more rapid decomposition of older

organic matter in the more highly oxygenated upper solum, and gradual translocation of older organics into the lower horizons. It follows that ages most closely approximating the initiation of pedogenesis should be obtained from deep in the profile, while assays from the upper solum in buried paleosols should most closely approximate termination of pedogenesis.

A second factor lies in the difference in age apparent in determinations on different humate fractions documented by several researchers (Scharpenseel 1979; Matthews 1980; Polach and Costin 1971). In general, apparent age increases through the successive decomposition products of humus, so that fulvic acid generally yields the youngest ages, hymantomelanic acid, brown humic acid, and gray humic acid yields intermediate ages, and humin yields the greatest ages (Goh 1980; Matthews 1985). This effect is believed to result from more pronounced decomposition and the higher rate of removal of the less stable acids.

Finally, a major complicating factor in assaying soils is the presumed tendency for active soil systems to reach a state of equilibrium, such that the rate of incoming fresh organic matter is equal to the rate of decomposition and leaching of older organic matter. In such situations, the apparent mean residence time theoretically stabilizes due to organic turnover as the age of the soil continues to increase (Martel and Paul 1974; Matthews 1980; Evans 1985), leading to increasingly erroneous estimates with older and older soils. However, there is little understanding of the timeframe necessary to achieve equilibrium in various types of environments, while the stability of many organic products (e.g., charcoal, some humus substances, opal phytoliths, some microbial enzymes) virtually eliminates the possibility of complete organic turnover (Matthews 1985). Still, the rate of turnover is clearly very rapid in warm arid environments, such as the Fort Bliss region.

Contamination of soils with older or younger carbon can occur through a number of different mechanisms. Additions of younger carbon, resulting in age underestimation, can result from root penetration, other forms of bioturbation and pedoturbation, cultivation, and other forms of anthropic disturbance, illuviation of finely divided organic matter and humic substances, and bacterial or fungal growth (Matthews 1985; Evans 1985). Additions of older carbon, leading to an overestimation of age, can result from the depositional inclusion of fossil carbon (e.g., graphite, lignite, old wood, fossil carbonates), or the incorporation of old carbon into organic compounds or soil carbonates derived from dissolution of fossil carbonates in groundwater (Geyh et al. 1971; Fowler et al. 1986; Geyh and Schleicher 1990). While considerably old carbon is necessary to substantially bias a radiocarbon age, the relatively high $^{14}\text{C}/^{12}\text{C}$ ratio in young carbon makes even minor contamination highly problematic.

Unlike soils, the problems and prospects associated with radiocarbon dating of sediments remain little explored. The principal reason that the radiocarbon method has not been widely applied to

mineral sediments probably lies in an assumption on the part of most investigators that radiocarbon age determinations on organic material from clastic sediments, like those from soils, are unreliable measures of the age of deposition. However, sediments are fundamentally different from soils in that organic matter is typically allochthonous rather than autochthonous and predates rather than postdates deposition. Moreover, salient chemical and environmental variables are typically less complex than is the case with soils, making suitability judgements and contextual interpretations somewhat easier in many cases.

The major assumption that must be made in dating sediments is that the organic material is penecontemporaneous and can provide a good estimate of the sediment age (Haas et al. 1986; Blum and Valastro 1989); if the organics have previously been in storage elsewhere (e.g., accumulating for thousands of years as a soil that is then converted to sediment by erosion), then the estimate provided can be significantly older than the age of deposition. Fortunately, this scenario is unlikely in the Fort Bliss region during the Holocene.

While soil ages provide only a minimum age for the onset of pedogenesis and sediments yield only a maximum age for their deposition, a combination of these two problems is presented by cumulic soils. In this situation, organic sediment, frequently containing older organic matter, accumulates slowly on a surface that is also undergoing contemporary pedogenesis and incorporating fresh organics; resulting ages can be either older or younger than the true age of sediment deposition, depending on a large number of interrelated pedogenic and geomorphic factors. Therefore, radiocarbon ages obtained from cumulic soils can be very difficult to interpret.

Radiocarbon dating of organic soils and sediments involves a complex sequence of pretreatment steps during which possible contaminants are removed and the organic carbon is concentrated (e.g., White and Valastro 1984; Haas et al. 1986). Determinations can be made on several different

humus fractions leached from the sample or on residual solid organic matter. Humin and humic acid, which are relatively stable compounds, are the most common humus fractions dated, while water-soluble fulvic acid is rarely dated due to its high mobility. Figure 13 presents a summary of the different routes that organic matter can take through the environment and the relationship between in-situ soils, cumulus soils, and sediments.

Several factors can be identified as important considerations both in evaluating the suitability of a sediment for radiocarbon dating and in interpreting the significance and possible implications of any ages obtained. The most important single consideration is the origin of organic matter incorporated in the fill. Ideally, sediments used for radiometric dating of stratigraphic sequences should ideally contain only penecontemporaneous organic matter, as fossil carbon and organics derived from other soils only introduce error. Unfortunately, in most situations the prospects for identifying the original source(s) of incorporated humus, and for evaluating the relative temporal context of the organic matter and the encasing sediment with any degree of confidence, range from extremely difficult to impossible. Nevertheless, it is possible to identify several characteristics that may indicate contamination with older carbon from eroding soils: (1) relatively high organic matter content; (2) variability or visual stratification in color due to organic matter differences; and (3) the presence of other soil constituents, such as carbonate nodules, reworked from original context.

A second major consideration in evaluating radiocarbon ages on alluvial sediment is the size of the catchment upstream from the point of deposition. Along with the addition of relatively organic-rich sediment from erosion of A horizons, old organic matter can be introduced bound to clays derived from the erosion of illuvial B horizons upstream. Although it can be assumed as a component, the odds of detecting the presence of this material prior to dating are negligible. Thus, fine deposits in a small catchment must always be considered suspect. However, if the distance of

transport is sufficient, washing of the clays can result in the release of much of this adsorbed organic matter prior to deposition (Tan 1982), improving the odds of obtaining an acceptable radiocarbon age.

Finally, like soils, sediments are subject to contamination by older or younger carbon after deposition and burial. The two major sources of contamination that should be evaluated are younger, intrusive organics delivered by root penetration or leaching of overlying humus, and older carbon delivered as dissolved bicarbonate in groundwater.

The following treatment presents a simplified conceptual model of four possible relationships between apparent age profile of a sediment column as measured by radiocarbon determinations on bulk sediment and the actual age of deposition. Figure 14 presents a graphic depiction of each model.

Contemporaneity, the situation represented by Figure 14A, is the ideal situation for use in age determinations. In this model, the ratio of penecontemporaneous organic matter to old organic matter is so high that the obtained age closely approximates the actual age of the sediments.

Figure 14B represents an idealized case of equilibrium loss of soils in catchment. In this model, organic matter exhibits an average residence span that remains relatively constant through time on the slopes of the catchment before being eroded and deposited as sediment. This is not meant to suggest that all organic matter in the system resides on the slopes for the same length of time, or even that all is converted to sediment.

Indeed, much of the total organic production is decomposing and being translocated deep into the profile, more is being immediately converted to sediment. The soil as a whole is experiencing no net degradation. What the model does depict is a balanced delivery of contemporary and stored organics, such that the average age of organics being delivered with the sediment does not change with time.

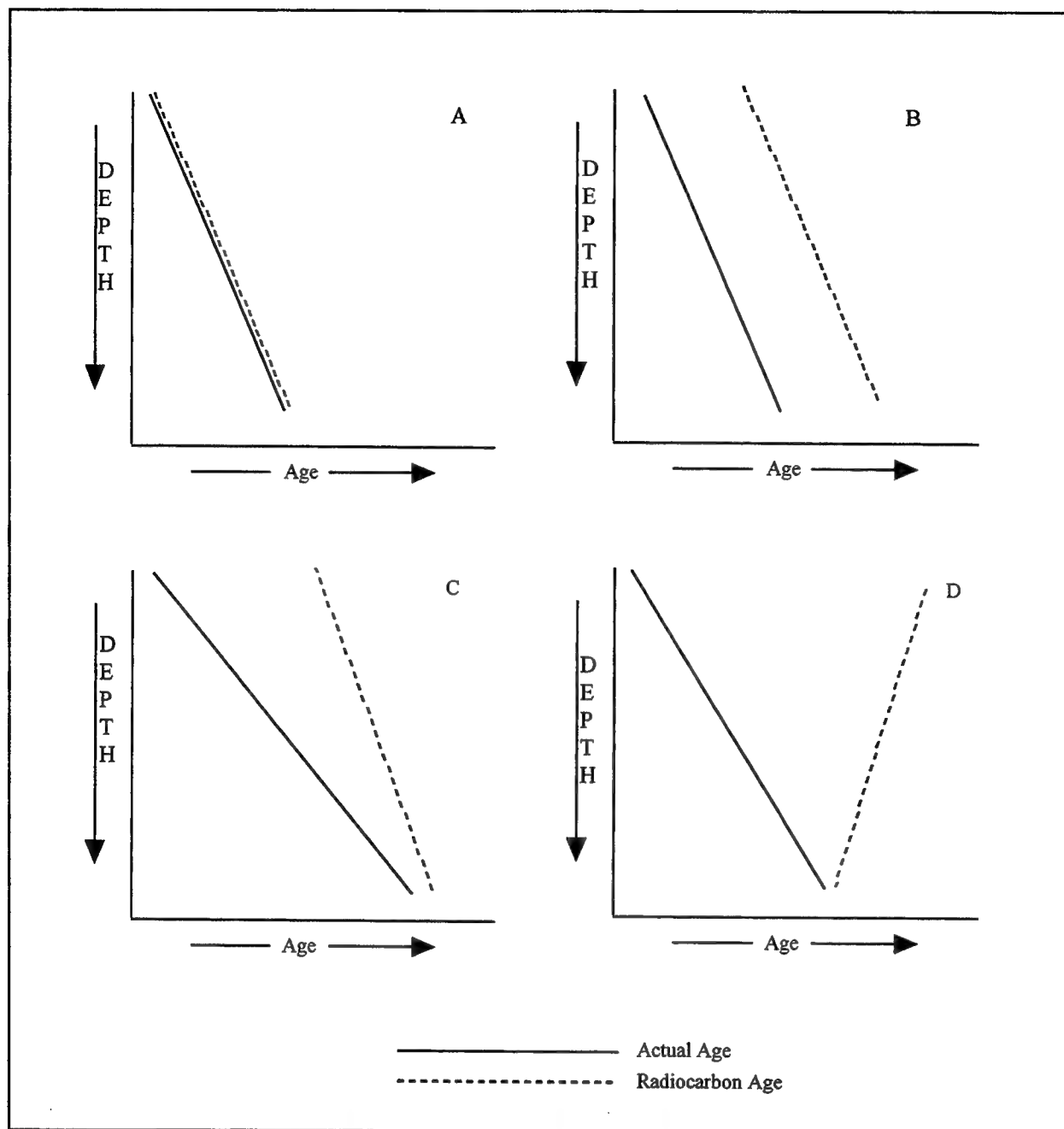


Figure 14 Idealized Models for the Relationship Between Actual Sediment Age and Apparent (Radiocarbon) Age in a Small Catchment Under Conditions of (A) No Soil Erosion; (B) Erosion in Equilibrium with Organic Production; (C) Accelerated Soil Erosion; and (D) Catastrophic Erosion.

Figure 14C represents a model of accelerated soil loss in the same theoretical catchment. Although the rate of sediment yield does not change dramatically, the soils in the catchment do begin to degrade. As a result, the ratio of old organics to contemporary organics being delivered increases. At the same time, the mean residence age of stored organic matter being delivered to the sedimentary system increases as the soil is degraded and the older organic matter at depth is converted to sediment.

Finally, Figure 14D represents a model of catastrophic erosion in catchment. Here, the sediment yield increases dramatically as the soils are degraded, and the age profile exhibits an apparent stratigraphic inversion as the normal age/depth profile of the basin soils is reversed due to deposition of the upper solum at the base of the sediment profile, followed by material derived from successively deeper in the original soil. Thus, the apparent age is almost entirely a function of reworked old organics. Note that the profile should return to the model presented in 2A after the soil has been exhausted.

In general, dating of sediments in arid alluvial fans and sandsheets has historically proven very difficult, which has led to the development of alternate methods of age determination (e.g., Dorn et al. 1986; 1987). However, the growing availability of AMS methods of radiocarbon dating reduces the carbon requirement by several orders of magnitude, suggesting that radiocarbon dating can be applied much more widely than it has been up to this point. One significant possible application is to anthropic humic substances. Many of the sites in the bolson are marked by the presence of ill-defined "stains" or localized dark discolorations of the sand, that are usually believed to be the remains of prehistoric features. The composition of these stains is poorly understood and probably variable; some may consist almost entirely of finely divided charcoal, while others probably include uncarbonized plant material and humic substances. Still others may be entirely composed of the latter material, and often probably represent in situ decomposition of a shrub

(particularly one that was buried by eolian activity), and thus are unrelated to cultural activity. In all cases, such stains are amenable to radiocarbon dating, although initial sediment processing may require vigorous methods and AMS measurement may frequently be required. AMS dating of dispersed, finely divided charcoal has proven to be a valuable technique in other regions (e.g., Gillespie et al. 1992).

4.1.4.4 Radiocarbon Dating of Soil Carbonates

Another use of radiocarbon applicable to the Fort Bliss region is dating of secondary carbonates, which has been applied in the region several times (e.g., Monger et al. 1993; Monger 1993d; Rightmire 1967). This technique can provide ages for geomorphic surfaces and episodes of pedogenesis, and can thus provide a measure of chronometric constraints on associated archeological sites. However, radiocarbon dating of carbonate is complex for several reasons. First, the complex development of indurated calcrete is a slow, nonuniform process (see Section 5.5); consequently, various contiguous parts of a caliche horizon can reflect strongly differing ages, and sample selection must be performed carefully (Goudie 1983). Even if internal structures are carefully noted and sampling is structured accordingly, hard water effects are a common pitfall, particularly in dating relatively advanced stages of calcrete (e.g., staged IV-VI) where solution and reprecipitation has probably occurred repeatedly. As water attacks and dissolves old indurated carbonates, dead carbon is released into the system, diluting the relative content of ^{14}C and making the determined age artificially old (Gile and Grossman 1979; Williams and Polach 1969; 1971).

4.1.4.5 Other Applications of Radiocarbon Dating

Another application that has great potential utility on Fort Bliss is radiocarbon dating of carbon incorporated in desert varnish (Dorn et al. 1986; 1987; Francis et al. 1993). Desert varnish is a colored coating (usually brownish-black) that develops on exposed rock surfaces in arid

environments. It is composed primarily of manganese and iron oxides, clay minerals, and silica, and is believed to have an aerosolic origin (Dorn and Oberlander 1982). Dorn et al. (1989) have demonstrated that rock varnish contains sufficient carbon to allow dating of this progressive surface crust, which can provide control for the initial exposure of the surface, particularly when the fraction dated is selected from the innermost, oldest varnish laminae. This is an example of the very significant utility of AMS radiocarbon dating, with its very small carbon requirement; no possibility exists for extracting enough carbon for conventional dating from this type of context.

Radiocarbon dating of pollen grains is also possible with the AMS method. This is significant because pollen grains are relatively resistant to degradation and can be preserved long after other organic remains are gone. Even more significantly, opal phytoliths also contain carbon. At least some of this carbon is occluded and therefore relatively protected from oxidation. Wilding (1967) demonstrated that this carbon is amenable to radiocarbon dating, while more recently Kelly et al. (1991) have recently demonstrated that stable carbon isotope ratios can be obtained from the carbon occluded in phytoliths. This is very significant because opal phytoliths, which are composed of silica, are very stable structures and provide an opportunity to date otherwise undatable strata. Of course, both pollen and phytoliths are highly subject to erosional reworking and vertical movement in section due to their small size, and great care is therefore required in sample selection.

4.1.5 Oxidizable Carbon Ratio Dating

Oxidizable carbon ratio dating, or OCR, is a promising new technique under development that may provide a cost-effective alternative to radiocarbon dating for obtaining ages from carbon-flecked sediments (Frink 1992; 1994; 1995). OCR dating is based on the observation that carbonized organic matter is not as stable as previously believed, and undergoes changes that can be measured using standard soil analytical techniques

(Frink 1992). In essence, OCR dating involves the comparison of oxidizable organic matter content as expressed by Walkley-Black wet combustion and total organic content as expressed by loss on ignition. Oxidizable organic matter only provides a measure of more reactive organic compounds, while loss-on-ignition provides a measure of total organic content. Frink has found that the ratio of these two fractions decreases linearly through time as the reactive components are removed at a higher rate. If the various environmental factors (e.g., temperature, moisture, soil texture and pH, and depth) are controlled, then the OCR ratio correlates quite well ($r=0.98$) with radiocarbon age, and can thus be used to predict the radiocarbon-equivalent age of unknown samples.

Control for the various environmental factors governing the rate of carbon loss is accomplished using the following formula:

$$OCRDATE = \frac{OCR \times Depth \times MeanTemperature \times MeanRainfall}{Mean\ Texture \times \sqrt{(pH)} \times \sqrt{(\%C)} \times 14.4888}$$

where OCR is the measured ratio between oxidizable carbon (per Walkley Black wet combustion) and total carbon (per Ball loss-on-ignition); depth is the depth below present ground surface in cm; mean temperature is the modern mean annual temperature in degrees F; mean rainfall is the modern mean annual precipitation in cm; mean texture is a specialized measure of texture determined by dry screening, pH is determined by measurement of a 1:1 soil/water paste; %C is percent carbon based on loss-on-ignition, and 14.4888 is an empirically-derived constant.

Although promising, OCR dating is a newly developed technique that employs a number of significant assumptions, and many problems with the method probably remain to be worked out. Several of these problems have already been identified, contraindicating application of OCR in some environmental situations (Frink 1995). For example, because anaerobic conditions change the character and rate of biological decomposition,

samples from contexts that were saturated, even intermittently, do not appear to be reliable. Similarly, samples from contexts that are sealed by impermeable strata, very deeply buried, or protected from precipitation (e.g., in a rockshelter) are problematic, because oxygen and moisture influx are not predictable by the existing equation. Samples with very low (<0.05%) carbon content (Frink 1994; 1995) have also proved problematic. In addition, one important factor downplayed by Frink (1995) may also prove important to application of the method on Fort Bliss; namely, the possibility that paleoclimatic fluctuations have significantly affected the rates of carbon loss over the Holocene period. While Frink recognizes this factor, he downplays it, arguing that deviations from modern mean precipitation and temperature and precipitation have been relatively minor during the Holocene and should not exceed the standard error of the OCR estimate (Frink 1995:100). Although this basic assertion is debatable, it does appear that environmental shifts were insufficient to seriously bias the samples addressed by Frink from the eastern United States. However, Fort Bliss is situated in a much more arid environment, and minor changes in precipitation could conceivably have major consequences for rates of biologic activity; consequently, the utility of the method to Fort Bliss will require careful evaluation.

Despite the uncertain applicability of OCR dating to Fort Bliss research problems, the method has tremendous potential to address the archeological record at Fort Bliss, particularly the myriad small hearths and areas of localized carbon stained sands in the bolson. The requirements for application (e.g., carbon flecked sediment, free drainage, no history of saturation, etc.) are well satisfied by these features. One of the advantages of the method is cost; roughly twelve OCR dates can be obtained for the price of a single AMS radiocarbon age. Perhaps most importantly, the OCR method does not suffer from the problems imposed on recent (i.e., less than 400 years BP) radiocarbon samples by the Suess Effect, DeVries Effect, and Atomic Bomb Effect (Bradley 1985), and therefore has the potential to effectively address

Protohistoric and Historic features plagued by the typically wide error factors of radiocarbon ages in this timeframe. Although OCR is clearly not a replacement for radiocarbon dating, it may prove to be a valuable and cost-effective adjunct for cross-checking and supplementing radiometric ages.

4.1.6 Fission-track Dating

Fission-track dating is based on the fact that spontaneous fission of ^{238}U atoms in microcrystalline rocks causes high-energy ejection of particles that can visibly damage the crystalline structure by ionizing atoms that come into contact with the fission products. Thus, the number of tracks is a function of the uranium content of the rock and the duration of fission events. If the former is known, then the latter can be estimated from the number of tracks per unit area (Hurford and Green 1982). Fission-track dating of archeological materials (e.g., lithic raw material, ceramics) is possible because heating can cause old tracks to heal in a process termed annealing, which essentially resets the clock (Michels 1973). If heating was insufficient to anneal the extant tracks, then dating of artifacts is not possible; however, there is little possibility of incorrectly dating an artifact in this manner because the derived age will be several orders of magnitude greater than it should be.

Fission-track counting requires that the surface be polished and etched with a solvent that preferentially attacks the damaged particle paths in the crystal lattice. Calculation is accomplished by counting the number of fission tracks in a representative area, heating the sample to anneal existing tracks, and then bombarding the sample with a slow neutron beam, which stimulates fresh fission of uranium. The number of tracks resulting from this treatment are proportional to uranium content, which allows the calculation of age.

In order to be suitable for fission-track dating of archeological phenomena in the Holocene timescale, the material must be relatively uranium-rich (but not too rich) and susceptible to annealing

with moderate temperatures. Suitable materials may include cherts, obsidian, a variety of minerals incorporated into ceramics, and apatite (calcium phosphate), which occurs extensively in bones, teeth, and shell.

4.1.7 Cosmogenic Isotope Dating

This category includes a number of different, emerging techniques that have the potential to date the length of surface exposure of rocks and artifacts. Although the original concepts are far from new (e.g., Davis and Schaffer 1956), the advent of modern particle accelerator spectrometry now allows for the high-precision determinations necessary for application. These techniques measure the production of cosmogenic nuclides; in other words, new isotopes created by the collision of existing atoms and cosmic rays. The same process is responsible for the creation of ^{14}C in the upper atmosphere, where cosmic ray flux is higher. The cosmogenic techniques measure generation of new isotopes due to cosmic ray influx in exposed surfaces at the ground, and are based on the assumption that cosmic ray flux is constant (not strictly true) and that the number of cosmogenic nuclides is proportional to the length of exposure (Kurz and Brook 1994; Cerling 1990).

Specific techniques in varying stages of development include ^{10}Be , ^{26}Al , ^{36}Cl , ^{14}C , ^{41}Ca , ^3He , and ^{21}Ne . These techniques can be divided into two classes: those that measure radionuclides and require an accelerator mass-spectrometer for measurement, and those that measure stable noble gas nuclides and can be measured with a noble gas mass spectrometer. Determinations based on noble gas nuclides are less complicated because they do not require adjustment for radioactive decay; they are also more problematic due to the potential for inherited isotopes. Table 8 illustrates the characteristics of each of the isotopes. Application of these methods to problems relevant to the Fort Bliss landscape has already begun (e.g., Wells et al. 1995).

Age determination requires measurement of the amount of the nuclide and determination of the rate

of radioactive decay and the rate of production, which is dependent on altitude, latitude, and depth below surface (normalized to units of equal density). When these factors are known, age can be determined by simply dividing the total amount of atoms of the nuclide in a given volume of sample by the net production rate, which is a function of production and decay. Complications arise when surface stability is not perfect, but corrections for slow surface erosion are possible (Kurz and Brook 1994).

4.1.8 Archeomagnetic Dating

Archeomagnetic dating is a correlation technique that can nonetheless provide relatively precise dates for fired features. It is based on the fact that heating of clays causes small regions (domains) within magnetic minerals contained therein to reorient. Normally randomly oriented, upon heating, these minerals behave like tiny dipolar magnets and align themselves with the earth's magnetic field in the same way that a compass needle points north. Upon cooling, the domains are locked into place, indicating the direction of the North Pole by their declination and inclination (Breiner 1973). Because the North Pole wanders with time, this information can be used to reconstruct the polar position at the time of feature use, once a curve indicating polar position is developed (Eighmy 1980).

4.1.9 Dendrochronology

Tree ring dating is based on the fact that trees add visually distinguishable annual growth rings composed of cycles of relatively light, high-growth season wood, and dense, low-growth season wood. Although many other factors (e.g., ring variations due to age and height of the tree) must be accounted for, the width of individual rings reflects in large part the vigor of growth on a year-to-year basis, and thus the response of the tree to climatic conditions. Because of this control, patterns in ring width are apparent between different trees (usually of the same species) within a limited geographic area. By counting backwards from the center ring of a living tree, it is possible to find the

Table 8 Cosmogenic Nuclides Used for Quaternary Surface Exposure Dating.

| Isotope | Half-Life (years) | Measurement Method | Procedural Comments | Approx. Production Rate (atoms/g/yr at sea level) | Approx. Age Range |
|--------------|--------------------|--------------------|--|---|-------------------|
| Helium-3 | stable | Mass Spectrometry | Diffusive loss? High production rate; lowest detection limit, inherited He | 160 (olivine) | 1 ka to ca. 3 Ma |
| Beryllium-10 | 1.5×10^6 | AMS | Atmospheric contamination | 6 (quartz) | 3 ka to 4 Ma |
| Aluminum-26 | 7.16×10^5 | AMS | aluminum-27 interference | 37 (quartz) | 5 ka to 2 Ma |
| Chlorine-36 | 3.08×10^5 | AMS | no mineral separates; composition-dependent | 8 (basalt) | 5 ka to 1 Ma |
| Neon-21 | stable | Mass Spectrometry | inherited neon | 45 (olivine) | 7 ka to 10 Ma |
| Carbon-14 | 5,730 | AMS | shortest half-life; atmospheric contamination | 20 (basalt) | 1 ka to 18 ka |
| Calcium-40 | 1.03×10^5 | AMS | Useful half-life, difficult measurement | unknown | to 300 ka |

After Kurz and Brook 1994.

calendar age of any ring within the tree. Correlation of patterns in ring width with old wood can extend that sequence farther back in time, provided that the fossil and modern sequences overlap sufficiently. Given a sufficient baseline, ages of wooden artifacts can be determined by matching a statistically standardized expression of the ring pattern to the continuous record, allowing the age of any ring within the tree (typically either the center ring, which approximates the year of germination, or the outermost ring, which approximates the year of death). If fossil curves cannot be connected to a living tree, a "floating" chronology (usually grounded with radiocarbon ages) can still provide a level of chronological control (Lowe and Walker 1984).

Although there are several extant tree-ring sequences from south-central New Mexico (cf. Mauldin 1995), the potential for dendrochronologic dating on Fort Bliss is hampered by the generally poor preservation of wood. However, applications of the technique are possible, and it needs to be

included in the arsenal of chronologic tools brought to bear on the problem.

4.2 QUASI-CHRONOMETRIC DATING TECHNIQUES

The following techniques are also sometimes used to obtain numerical ages through calibration with independently derived chronometric data. They are classified as quasi-chronometric here because the precision and/or utility of the methods remains somewhat controversial.

4.2.1 Obsidian Hydration

Obsidian-hydration dating is a relative dating technique that can be extended through correlation to provide numerical age estimates (albeit with large error factors). Obsidian hydration is based on the fact that freshly exposed obsidian surfaces take up water from the environment, forming a hydrated obsidian termed perlite. Hydration rind development slows with time, but overall thickness

of the rind is a nonlinear function of time, temperature, and obsidian chemistry (interestingly, variability in humidity has little effect on the rate of hydration); thus, examination of the thickness of the rind (which is accomplished optically in thin-section) provides a good estimate of the relative age of the surface. This makes the technique ideal for relative dating of obsidian flakes in intrasite and regional contexts (Bradley 1985; Lowe and Walker 1984).

Obsidian hydration can also provide quantitative, material-dependent, and location-dependent estimates of age when calibrated to an independent time scale. Obsidian hydration follows this diffusion law:

$$M^2 = Kt$$

where M = hydration rind thickness in microns; K = the diffusion coefficient; and t = time. The diffusion coefficient K is a function of several variables, notably the chemistry of the obsidian (which will not change appreciably with time) and the temperature (which does change with time, and is largely a function of climatic change and burial history). Thus, the rate of hydration can be expected to change through time, not only as a function of increasing rind thickness (which slows the rate logarithmically, and is thus predictable), but also as a function of climatic change and burial history. These latter factors are difficult to factor in and are therefore typically ignored; K is considered a constant. Nevertheless, once curves are constructed for commonly occurring varieties, obsidian hydration can provide valuable, albeit approximate, chronometric estimates (Michels 1973).

4.2.2 Chert Patination

Patination of chert is similar to obsidian hydration in that it involves progressive alteration of the surface of a freshly fractured artifact (Hurst and Kelley 1961). Several different types of patinas have been reported in the literature, including whitish patinas, brownish patinas, and glossy

patinas. While white patinas are probably the most common and most likely represent a subtractive process (i.e., silica dissolution), the character of glossy and brown patinas may be either additive (e.g., staining by ferric or humic substances), subtractive, or indicative of in situ changes such as oxidation of extant components. A number of environmental and material-specific variables, including edaphic conditions, temperature, mineralogy, porosity, and permeability have been identified (VanNest 1985). Moreover, differential patination of different sides of artifacts is very common, suggesting at least a degree of photochemical control on patination rates. In short, little is understood about the various physical transformations commonly included under the rubric of patination (Frederick et al. 1994; VanNest 1985). Nevertheless, quantification of progressive patination has been proposed as a possible dating technique (e.g., Purdy and Clark 1987).

The utility of patination as a chronometric dating technique is limited by the many factors outlined above, coupled with uncertainties of burial inherent in a dynamic environment. In a study of patination of time-diagnostic chert artifacts on Fort Hood, Texas, Frederick et al. (1994) found that while the maximum degree of patination across an artifact class appeared to be largely a function of age, the degree of patination of individual artifacts within that class could vary widely. Thus, once calibrated to an independent chronometric scale, patination appears potentially suitable for establishing a minimum age in that artifacts with a patina rind of thickness X can be no younger than the time necessary for that rind to develop; unfortunately, the presence of that rind in no way implies that the artifact is exactly that age. Moreover, a lack of patination has no implications for age whatsoever because many factors appear to be able to slow the rate of patina development.

4.2.3 Amino Acid Racemization

Amino acid epimerization analysis involves the measurement of the ratio of the amino acid epimers D-alloisoleucine and L-isoleucine, referred

to hereafter as the A/I ratio, in a carbonate matrix (Miller 1980; McCoy 1987). The method is typically applied to gastropod shells (e.g., Goodfriend 1987; Ellis and Goodfriend 1994), which are the focus of this discussion, but has also been applied to calcite speleothems (e.g., Lauritzen et al. 1994).

In modern specimens, essentially all amino acids are in the L-form, but over time they chemically convert (epimerize) to the D-form. The rate of conversion is a function of temperature, but is consistent enough that the A/I ratio can be used as a proxy measure of relative age, and can provide an approximation of absolute age when tied to an independently derived chronometric scale (Goodfriend 1987; Ellis and Goodfriend 1994). Although some moisture must be present for the epimerization reaction to occur, the most important variable involved is heat, which governs the rate of conversion. Significantly, for archeological studies, snails subjected to substantially elevated temperatures (e.g., in a fire) for short periods of time appear to rapidly epimerize during heating, resulting in ratios that resemble substantially older specimens.

Another factor that may affect the relationship between A/I and age is slope-aspect. One of the implicit assumptions of the A/I method is that the rate of reaction is equal in the spatial realm within the boundary of a given study area. In other words, while the rate of the reaction is recognized to vary temporally due to changes in climate, it is assumed to be equal at all locations within a limited geographic area at a given point in time. However, because elevation and aspect strongly influence soil temperature, snails from different topographic/edaphic settings may not be strictly comparable.

Nevertheless, recent research (e.g., Ellis and Goodfriend 1994) suggests that amino acid racemization of landsnails may provide relatively good chronometric data if interpreted carefully. Moreover, such research also has the potential to provide valuable information about the integrity of

buried archeological assemblages, and is relatively inexpensive to perform (Ellis et al. 1994).

4.2.4 Cation-Ratio Dating

Another technique of dating surfaces in deserts is termed cation-ratio dating, which examines the ratio of soluble (potassium and calcium) versus insoluble (titanium) cations in desert varnish (e.g., Dorn and Oberlander 1982; Dorn et al. 1987). According to Dorn and his coauthors, this ratio decreases with time in a fashion that is regular enough to provide chronometric control once calibrated to an independent scale (typically through AMS radiocarbon dates on the varnish). However, several recent critics (e.g., Bierman and Gillespie 1994; Harry 1994) present compelling evidence that the uniformity necessary for use of the process as a chronometric dating technique does not exist. Therefore, the technique is probably best treated as a relative dating method at this time.

4.3 RELATIVE AND CORRELATIVE DATING TECHNIQUES

This final suite of methods consists of interpretive techniques that can be used to obtain qualitative estimates of age. They are typically the first suite of chronometric tools applied at a given site, and usually dictate whether other, more precise methods will be applied.

4.3.1 Soil Development

Because soil development is a time-dependent process (see Section 5.4), the degree of alteration that has affected a sediment is in large part a function of the duration of pedogenesis. For this reason, examination of the development of various soil attributes can be used to construct a soil chronosequence, which provides a rough indication of the age of different soils formed in similar parent materials under equivalent topographic, climatic, and biotic influences (e.g., Harden 1982; Singer and Janitzky 1986). Such a method can be applied relatively loosely by simply making field observations, which is probably most common, or

it can be applied rigorously using precise laboratory measurement of various criteria. Although the latter approach can increase the precision of the estimate considerably and will even allow a rough numerical estimate of age in some cases, the large number of variables suggests that the technique is still best treated as a relative dating method.

Almost any type of pedogenic modification can be used as a rough indicator of age. At the less rigorous end of the scale, characteristics observed in the field (e.g., horizon sequence, degree of horizonation, soil thickness, soil texture, soil structure and consistency, organic matter accumulation, clay accumulation, degree of carbonate leaching, amount and morphology of carbonate accumulation, visibility of primary strata, rubification, degree of bioturbation) are typically used to assign the soil, and by implication the surface that the soil is developed in, to broad age categories (e.g., recent, Late Holocene, Early-Middle Holocene, Late Pleistocene-Early Holocene, etc.) (Birkeland 1984). If laboratory characterizations (e.g., carbonate, iron, texture, organic matter, pH) are used to characterize dated soils, then the estimated age of soils can frequently be refined (Singer and Janitzky 1986). In addition, similar techniques can be used to roughly estimate the length of depositional hiatuses represented by buried paleosols intercalated in stratigraphic sequences. However, because climate plays such a dominant role in the rate of soil formation, the expression of surface soils formed primarily under previous climatic conditions can be almost identical to contemporaneous soils that were subsequently buried, even though the two soils experienced very different soil-forming intervals (Birkeland 1984).

4.3.2 Geomorphic Position

Geomorphic position can be used to provide relative dating of archeological sites in some cases because the architectural relationships between different landscape elements are frequently dictated by the sequence of formation; thus, in situ archeological sites associated with a landform can

be no older than the landform that they occupy. Thus, an archeological site interstratified within an older terrace can be assumed to predate another site interstratified in a younger, inset terrace. In contrast, an archeological site resting on top of the older terrace may be of any age younger than the age at which the terrace stabilized. Care must be taken in addressing shallowly buried sites in such a context also, because slow, incremental deposition can still occur on an effectively abandoned surface syncontemporaneously with aggradation of the inset fill; thus, a shallowly buried site may be significantly younger than the landform on which it rests. Reworking is also a problem to be considered because an older site can be eroded from its original context and incorporated into a younger fill.

4.3.3 Stratigraphy and Superposition

Stratigraphy is one of the most heavily relied upon methods of determining age relationships between components at an archeological site. The law of superposition states that in undisturbed sediments or rocks, each stratum is older than all strata above it and younger than all strata beneath it (Bates and Jackson 1984); therefore any excavation should encounter increasingly old deposits and associated artifacts with depth. However, the latter implication is not necessarily true, because while the age of the strata will follow the law, objects contained in the strata can be reworked through erosion or excavation, and thus may not rest in their original context. In one extreme form, archeological sediments can exhibit reverse stratigraphy, where the age of artifacts actually decreases with depth (Schiffer 1987). This type of stratigraphy can be formed by earthmoving, or by the successive erosion and downslope redeposition of a thick archeological sequence. A more common and insidious type of problem is presented by stratigraphic complexity. Although there is a marked tendency to treat archeological sites as if they have layer-cake stratigraphy testing, and to correlate recovery in terms of depth below surface, particularly during interpretation of small, noncontiguous units excavated during testing, it is probably accurate to state that most stratigraphic

situations do not conform to this ideal picture. Rather, local variations in rate and process in vertically aggrading systems, variability and localization of erosional processes, and the influence of laterally-aggrading systems (e.g., point bars, migrating sand dunes) combine to complicate the picture. Usually, such effects can be eliminated by careful recording of the stratigraphy, but occasionally the pedogenic overprint is so pronounced that the original stratigraphic boundaries cannot be reliably identified.

Although stratigraphy in a strict sense is usually restricted to examination of individual sites, similar concepts can often be applied at a regional scale through the construction of a broadly applicable soil-stratigraphic framework. Such a framework utilizes sedimentologic properties, soil criteria (see Section 4.3.2), topographic criteria, and/or architectural relationships between depositional units to devise a model of stratigraphy that can be used for rough age interpretation at a variety of sites (e.g., Blum et al. 1992; Frederick 1993; Ferring 1986; Mandel 1987; Nordt 1992). The general frameworks for eolian and alluvial fan deposits in the Tularosa/Hueco Bolson (Doleman and Blair 1991; Monger 1993e; Gile et al. 1981) are local examples of such a framework. One important aspect of such frameworks is that they should be considered evolving entities and revised as additional data becomes available.

4.3.4 Artifact Seriation and Crossdating

Together with stratigraphic superposition, artifact seriation and crossdating are the oldest methods of relative dating employed in archeology. Seriation is a process where attributes of an artifact class are ordered chronologically. It is based on the assumption that artifact attributes (particularly stylistic attributes, such as shape and decorative motifs) come into and go out of fashion. In the process of seriation, artifacts representing the same cultural tradition are arranged to trace these stylistic changes through time; thus specific artifacts can be determined to be "time-diagnostic" relative to that tradition. Crossdating refers to the common assumption that a diagnostic artifact

found at undated locality B will represent a similar timeperiod as the same type of diagnostic artifact found at dated locality A, and that the assemblage at locality B is therefore roughly the same age as the assemblage at A (Champion 1980). Although there are many potential problems with these approaches (not the least of which is reuse of found "heirloom" artifacts by later peoples), they have proven very useful and are used widely in North American archeology, particularly for projectile points and ceramics.

The use of various projectile point types as a relative dating technique in the Fort Bliss region is hampered by the overlapping presence of a variety of different stylistic traditions, including the Oshara tradition from northern New Mexico (Irwin-Williams 1973; 1979), the Cochise tradition from southern Arizona (Sayles and Antevs 1941), and the Trans-Pecos tradition from west Texas (Mallouf 1985). These point types, and the traditions of which they form a component, are typically dated outside of the Jornada region. Within the Jornada, most point types are poorly dated as there have been few excavations with both sufficient sample size, stratigraphy, and associated chronometric dates.

The point typology outlined in Table 9 is based primarily on the work of MacNeish (1993) at Todson cave, and his summaries of the Fresnal and La Cueva Material, work at Fresnal shelter reported by Jones (1990), and surface collection data reported by O'Hara and Elyea (1988) and Carmichael (1986a). These data sources are supplemented by general overviews supplied by MacNeish and Beckett (1987), Beckes (1977a), Gossett (1985), Sayles and Antevs (1941), Suhm and Jelks (1962), Turner and Hester (1985) and Mallouf (1985). All dates are reported in years before present (BP). A "+" on either end of the date range indicates that there are reports of the point type dating either earlier or later than the assigned date. Priority for probable date ranges is given to the local area rather than the original description of the type. Drawings and metric descriptions are available for most types in

MacNeish (1993), Jones (1990), and O'Hara (1988).

Ceramic types presented in Table 10 are better dated than their projectile point counterparts, especially outside the Jornada area as in several cases they are associated with tree-ring dates (see Breternitz 1966; Carlson 1970; Smiley 1977). The local ceramic sequence, minimally consisting of El Paso Brown, El Paso Bichrome, and El Paso Polychrome, is dated by association with radiocarbon dates and cross dating with other types outside of the local region (Hard et al. 1994; Whalen 1981b). The Mimbres sequence, with the tripatrie style distinction primarily on ceramic bowls (Shafer and Taylor 1986; Scott 1983), is the only sequence that approaches a classic frequency seriation in that it appears to rely primarily on stylistic attribute changes. The remaining types are essentially a combination of seriation and "fossil directors," and are closely linked to cultural history notions of interaction.

Finally, several researchers have noted patterned variability in rim form attributes within the local ceramic sequence that seem to vary with time. Lehmer (1948:94) first observed differences between El Paso Brownware rims, which were often pinched, and El Paso Polychrome rims, which are thickened and everted. Beginning in the late 1970s, a number of researchers attempted to develop a seriation of rim attributes based on these changes in rim form (see Whalen 1978; West 1982; Carmichael 1986a). Whalen (1978:58-70; 1980) suggested that within the long Mesilla phase, the El Paso Brownware ceramic sequence could be subdivided into early and late periods based on the degree of tapering in rims, with early rim lips being "tapered" and later rims having a more flattened profile.

West (1982) attempted to quantify aspects of the thickening of rims with the Rim Sherd Index (RSI), based on standardized measures of thickness at 2 cm and 15 cm below the lip of a rim. Carmichael (1986a) used the RSI to assign sites to phases, demonstrating that the mean RSI increases between sites assigned to the Mesilla, Doña Ana,

Table 9 Common Projectile Point Types and Their Probable Date Ranges for the Jornada Region.

| Type Name | Probable Date Range (BP) | Reference* |
|----------------|--------------------------|------------|
| Clovis | +12,500 - 11,000 | 1, 3 |
| Folsom | 11,000 - 10,000 | 1, 3, 4 |
| Angostura | 10,000 - 9000 | 1, 3 |
| Jay | 8000 - 6000+ | 1, 2, 3 |
| Bajada | 8000 - 6000+ | 1, 2, 3 |
| Lerma | 9000 - 6000+ | 1, 3 |
| Amargosa/Pinto | 6500 - 4500 | 1 |
| Augustin | 6000 - 3000 | 1, 2, 3 |
| Todson | 5500 - 4000 | 1 |
| San Jose | +4500 - 3000 | 1, 2, 3 |
| Chirichaua | +4500 - 3000 | 1, 2, 3 |
| Maljamar | 4500 - 2000 | 1 |
| Fresnal | 4500 - 2000 | 1, 2 |
| Hueco | 3000 - 1500 | 1 |
| Pendejo | 3000 - 1500 | 1 |
| San Pedro | 3000 - 2000+ | 1, 2, 3 |
| Coahila | 3500 - 3000 | 2 |
| Scallorn | 1500 - 600+ | 1, 3 |
| Toyah | 1000 - 600+ | 1 |
| Harrell | 1000 - 500+ | 1, 3 |

* 1 = MacNeish (1993); 2 = Jones (1990); 3 = O'Hara (1988); 4 = Amick (1994).

and El Paso phases. While questions exist regarding changing vessel shapes (see Hard et al. 1994; Seaman and Mills 1988), these studies suggest that RSI may be useful at a phase level. Whalen (1978, 1980, 1993) has conducted a variety of within-phase studies of rim form changes. In the most recent study, Whalen (1993) used rim sherds from dated contexts at the site of Turquoise Ridge to consider the potential of rim form changes within the Mesilla phase. Using RSI values, Whalen notes that, while there is no significant difference expressed in such values through time, there is a "tendency" for RSI values

Table 10 Common Ceramic Types and their Probable Date Ranges for the Jornada Region.

| Type Name | Probable Date Range (BP) | Reference* |
|--------------------------------|--------------------------|------------|
| El Paso Brown | 1700 - 750 | 1, 2, 5 |
| El Paso Bichrome | +1000 - 700 | 5 |
| El Paso Polychrome | +800 - 500+ | 2, 5 |
| Mimbres Black-on-white Style 1 | 1200 - 1000 | 3, 4 |
| Mimbres Black-on-white Style 2 | 1000 - 950 | 3, 4 |
| Mimbres Black-on-white Style 3 | 950 - 800+ | 2, 3, 4 |
| Chupadero Black-on-white | 850 - 550+ | 1, 6 |
| Gila Polychrome | 850 - 550+ | 1 |
| Villa Ahumada Polychrome | 900 - 550+ | 1 |
| Ramos Polychrome | 900 - 450+ | 1 |
| Lincoln Black-on-red | 750 - 550+ | 1, 8 |
| San Andres Red-on-terracotta | +950 - 650 | 1, 8 |
| Three-Rivers Red-on-terracotta | 800 - 650+ | 1, 8 |
| Playas Red | 950 - 450+ | 1 |
| St. John's Polychrome | 800 - 650 | 1, 7 |

* 1 = Smiley (1977); 2 = Whalen (1981); 3 = Scott (1983); 4 = Shafer and Taylor (1986); 5 = Hard et al. (1994); 6 = Wiseman (1982); 7 = Carlson (1970); 8 = Breternitz (1966).

to increase after about A.D. 900. He also demonstrates that flattened rim forms are somewhat more common later in time. Unfortunately, changes in both of these measures are minimal, thus obviating most uses of such data for intra-phase assignment (see Whalen 1993:484-485).

Developing a useful seriation for assigning sites based on rim form variation is hampered, then, by a lack of strong intraphase changes in rim attributes and problems with variations in vessel form that may have been functional rather than stylistic. While these data support Lehmer's original characterizations of rim form change, additional research is clearly necessary before extensive use of measures such as RSI to assign sites or components to phase or intraphase periods.

4.4 RESEARCH QUESTIONS

The suite of dating methods outlined in this chapter are clearly not equally applicable to archeological questions on Fort Bliss. Although they are reliable, the timeframes addressed by many of the methods (e.g., Uranium series, and lead isotope) are either too old or too young to be applicable to most archeological questions on Fort Bliss; however, these methods have been briefly included here because they could potentially prove useful to investigation of protohistoric/historic or "pre-Paleo" components. Other quantitative methods, notably the various forms of luminescence dating, ESR, Cosmogenic Isotopes, and OCR, have tremendous potential for addressing the Fort Bliss archeological record, but are handicapped by their experimental nature, lack of wide availability, and frequently long turn-around time. The quasi-chronometric techniques (e.g., obsidian hydration, chert patination, racemization,

and cation-ratio dating) are generally less reliable than the chronometric techniques, and should be used only to supply supplemental data. Dendrochronology has good potential, but is strongly handicapped by the paucity of preserved wood in sites on Fort Bliss. Archeomagnetism also has good potential, but requires fired clay-rich sediment. Radiocarbon dating is clearly the single preferred method for dating Holocene archeological phenomena. However, as the preceding discussion has hopefully demonstrated, the radiocarbon method needs to be applied and interpreted with care. Finally, because not every aspect of an individual site or the broader landscape can be sent to a laboratory for dating, the relative and correlative techniques need to be applied rigorously and systematically, building on the framework provide by numerically-dated samples.

The following questions outline basic fundamental applications of the previously described techniques to archeological problems on Fort Bliss. For the most part, they are questions of applicability and appear somewhat trivial when formally stated. Nonetheless, they are crucial to deciphering prehistory in the region. Data requirements for each question are self-evident.

- | | | | |
|-----|--|-----|--|
| 4-1 | To what extent can AMS radiocarbon dating be exploited to address chronological problems on Fort Bliss? Are organic/charcoal "stains," which are probably the most common type of feature in the eolian environment, amenable to routine dating, or are costs prohibitive? What use are radiocarbon dates on pedogenic carbonate? On shell and bone? On soil and sediment? | 4-3 | What are the practical applications of electron-spin resonance dating to archeological problems on Fort Bliss? Can the technique be used to efficiently date lithic debris? Ceramics? Bone? |
| 4-2 | To what extent is the application of luminescence dating to the eolian deposits on Fort Bliss practical? Can other deposits (e.g., playa, alluvial fan) yield reliable ages? Do the advantages of luminescence outweigh the expense and timeframe involved in dating the technique; in other words, can | 4-4 | Can cosmogenic isotopes be employed as a routine method for dating surfaces and surficial deposits on Fort Bliss? Which isotopes are least problematic, and what is the comparability of their results to each other and to more conventional techniques like radiocarbon? Can a single isotope eventually be identified as a "best fit" for each particular situation to reduce costs and turnaround, or should multiple isotopes be addressed in each situation? |
| | | 4-5 | Are fission track ages on local lithic materials reliable and cost-effective for Fort Bliss? Is uranium present in sufficient amounts in the local cherts to be an effective means of dating materials only a few thousand years old, and do the materials anneal sufficiently with heating in an open fire? |
| | | 4-6 | Are fired features at Fort Bliss amenable to archeomagnetic dating? How well do the results agree with other lines of chronologic information? In other words, how accurate does application of the generalized southwestern archeomagnetic curve appear to be? |
| | | 4-7 | Is dendrochronology ever practical at Fort Bliss, or is usable wood entirely absent? |

common application of OSL and IRSL be justified?

-
- 4-8 To what extent can obsidian hydration and patination be used for relative dating? Can these techniques be used to help discriminate between temporal elements in a palimpsest occupation?
 - 4-9 Are landsnails amenable to racemization dating present on Fort Bliss? Are they common enough to warrant construction of an A/I calibration curve? How well do changes in the A/I ratio correlate with independently derived ages?
 - 4-10 How useful to Fort Bliss archeological questions is cation-ratio dating of rock varnish?
 - 4-11 How can the soil-stratigraphic framework of the region be revised to yield more accurate estimates of age?
 - 4-12 How can the regional sequence of diagnostic artifacts be expanded and refined to allow for more common or accurate age estimates?
 - 4-13 How applicable is Oxidizable Carbon Ratio dating (OCR) to problems on Fort Bliss?
-

5.0 GEOARCHEOLOGICAL RESEARCH DOMAIN

James T. Abbott

This chapter develops discussions of geoarcheological issues relevant to Fort Bliss. Five basic issues are addressed: eolian processes and landforms, alluvial fan processes and landforms, slope processes and landforms, arid lacustrine processes and playas, and soils. Each of the first four sections includes background discussions of relevant processes, characteristic landforms, climatic and geoarcheological implications of the processes and landforms, and research questions arising from the discussion. The soils section addresses pedogenic processes and the implications of those soil-forming processes for landscape reconstruction and site disturbance. The chapter concludes with a brief discussion of the relevance of context to archeological investigations on Fort Bliss.

5.1 EOLIAN PROCESSES AND LANDFORMS

Eolian processes represent one of the most important and pervasive mechanisms of Holocene landscape change in the study area, and thus have tremendous import to questions of site formation, integrity, and visibility. This section summarizes essential background information on generalized eolian processes and bedforms, climatic implications of eolian deposits, and generalized geoarcheological considerations pertinent to archeological sites in eolian settings. The following section applies this information to a discussion of the eolian deposits of Fort Bliss, and then discusses implications for the archeological record.

5.1.1 Eolian Processes

Like water, moving air is a fluid, and behaves much the same in its ability to entrain, transport, and deposit sediment. The two principal differences between air and water as mediums of sediment transport are differences in density and in the uniformity of flow (Summerfield 1991). Air

is, of course, much less dense than water; as a result, the size of eolian clasts is limited by mass restrictions to grains the size of sand or smaller, while alluvial clasts can weigh many tons (Lancaster and Nickling 1994). A more subtle but equally important distinction is that eolian processes are not strictly controlled by preexisting topography; thus, while the vector of transport in alluvial systems is relatively constant (i.e., downhill), eolian systems are subject to strongly variable flow vectors, and thus do not exhibit nearly the same degree of topographic control.

Eolian transport is accomplished when the tractive forces imposed by wind on surficial sediment grains exceed the net resistance to movement imposed by grain mass and shape, friction, packing, and interparticle cohesion. These tractive forces include two force vectors, termed lift (the vertical component) and drag (the horizontal component) (Greeley and Iversen 1985). As wind speed exceeds the necessary threshold velocity, resistance is overcome and the particle begins to move. Eolian particles can move in any of three forms: as suspended load, held in the air column by turbulence; as saltating load, alternately lifted into the air column and returning to the earth; and as traction load, rolling and sliding at the air/ground interface in a process termed surface creep. In any given system, the coarsest particles undergoing transport (typically very coarse sand-sized or below) are in the traction load (also commonly termed surface creep), intermediately sized (typically medium to fine sand-sized or below) particles are in the saltating load, and fine particles (typically silt-sized and below) are in the suspended load. While suspended sediment grains can be carried hundreds or thousands of feet into the air column, and thus move considerable distances before returning to earth, saltating particles only rise a few feet off the ground and move a few feet forward with each "hop."

Saltation is the primary mechanism of movement in most sandy systems (Bagnold 1941). As the threshold wind velocity is exceeded, the grain

detaches from the surface and rises almost vertically for a short period until the pull of gravity takes over, returning the particle to earth in a parabolic arc, and striking the surface at a relatively low angle (typically between 10° and 16°) (Bagnold 1941). As the grain returns to earth, it impacts other particles, imparting energy that can stimulate those particle to move. This subsequent movement can either be a minor shift caused by the force of the impact alone in a process termed reptation (Ungar and Haff 1987), or can provide the necessary impetus to initiate saltation of the impacted grain; the impacting grain, too, tends to rebound and thus continue saltating. As a result of this additional energy, wind velocity can fall below the initial threshold speed without causing transport to cease. Thus, two threshold wind speeds, termed the fluid threshold (which must be exceeded to initiate movement) and the impact threshold (which wind speed must drop below in order for movement to cease), are unique to eolian systems. Empirical observations have demonstrated that the fluid threshold is lowest for particles in the fine to very fine sand-size range; particles of larger size are increasingly inhibited by mass, while smaller particles are inhibited by interparticular attraction (Bagnold 1941). However, once saltation of sand grains is initiated, saltation impacts can dislodge finer particles, initiating their entrainment (Lancaster and Nickling 1994).

Eolian transport and deposition require that several prerequisite conditions be met. First, there must be a source of suitable sediment. As stated above, sand-sized particles are much more prone to eolian entrainment than silt and clay particles because of intrinsic differences in interparticular cohesion. However, the inherent resistance to abrasive entrainment by saltating particles of a sediment is a function of the relative proportion of different sized particles; just as the addition of gravel to cement to form concrete increases its resilience, the inclusion of moderate amounts of sand increases the resistance of dominantly fine-grained sediments to eolian entrainment (Chepil and Woodruff 1963).

Further, eolian transport typically requires that the source sediment is dry and noncohesive. Even in sands, relatively low moisture contents can significantly inhibit necessary threshold velocities, which typically show an exponential increase in resistance to entrainment with increasing moisture content (Azizov 1977). Other factors contributing to differences in internal cohesion include the relative content of bonding agents, including silt and clay, organic matter, and soluble salts. Even in sediments where internal cohesion is low, entrainment can be inhibited through the formation of surface crusts by raindrop impacts, algae and fungi growth, or salt precipitation (Lancaster and Nickling 1994). In these cases, disruption of the surface crust by grazing animals or off-road vehicles can result in rapid deflation. On the other hand, drying and salt precipitation can also lead to the disruption of surface crusts, facilitating entrainment.

Finally, surface roughness conditions must be conducive to entrainment. On a perfectly smooth surface, friction between the moving air and the surface, and the resulting shear stress imposed, is distributed evenly, which causes a logarithmic reduction in wind speed in the boundary layer. However, in the case of rough surfaces, shear stress is distributed unevenly, with higher elements of the surface experiencing relatively greater stress. This effect is enhanced by increased turbulence in the boundary layer as air flow is distorted by surface obstacles, decreasing fluid competence. The degree of inhibition is a function of the size, arrangement, character, and spacing of surface obstacles. Thus, because of this disruption of flow in the boundary layer, effective surface armoring by plants and/or gravelly lag deposits does not require continuous coverage of the erodible substrate.

5.1.2 Eolian Landforms

Landforms resulting from the action of eolian processes can be divided into two broad classes: erosional forms, which resulted from the net removal of material through eolian entrainment (deflation) or from mechanical abrasion of the

surface by (typically sandy) material in transport, and depositional forms, which resulted from the net accumulation of transported material.

5.1.2.1 Erosional Eolian Landforms

A large number of erosional eolian landforms are known, but only a subset of these occur within the region occupied by Fort Bliss. Several of the more exotic erosional forms, including yardangs (humpbacked, streamlined erosional forms typically formed in nonindurated, fine-grained sediments) and well-developed ventifacts (faceted stones that have been abraded and polished by wind-borne grit) have not, to our knowledge, been reported in the Fort Bliss region.

The most widespread type of feature on Fort Bliss that is commonly cited as evidence of eolian erosion is the abundant fan surfaces mantled with a relatively continuous carpet of coarse gravel. This phenomenon occurs in many arid environments, and is termed desert pavement in North America, reg in northwest Africa,serir in northeast Africa, and gibber in Australia (Whittow 1984; Dixon 1994). Hamada is a related Arabic term, which refers to bare rock surfaces mantled with coarse debris presumably left over after all the fines have been winnowed away. Although the classic model of desert pavement development focuses on eolian winnowing of alluvial deposits, resulting in a concentrated deflation lag of coarse clasts (Whittow 1984; Cooke 1970; Dan et al. 1982), this model has been challenged recently (e.g., McFadden et al. 1987; Dixon 1994; Wells et al. 1995). Dixon (1994) identifies five processes that have been cited as mechanisms of pavement formation: (1) winnowing of surface fines by eolian deflation; (2) winnowing of surface fines by overland wash processes; (3) upward migration of stones due to expansion/contraction associated with wetting and drying or freeze-thaw cycles; (4) deposition and infiltration of eolian sand and dust on an existing pavement, coupled with slow downslope transport of the pavement, resulting in eolian accumulation beneath the stones; and (5) more rapid subsurface weathering, resulting in breakdown of coarse clasts below the surface. In

addition to these five models, turbation by burrowing rodents is an additional mechanism of gravel introduction that can contribute to the surficial gravel mantle. While none of these models is probably the sole mechanism of pavement formation, it seems clear that eolian deflation is not the only mechanism operating to create desert pavements.

Playas, or ephemeral lake basins, are also frequently identified as geomorphic features that develop largely through eolian deflation; however, this model too remains somewhat controversial, and other mechanisms have also been proposed (see Section 5.4).

Blowouts are phenomena characteristic of areas where stabilized, erodible sediments are disrupted, causing wind erosion (Figure 15). Blowouts are commonly associated with removal of protective vegetation, but can also occur where any type of surface disruption destroys an erosion resistant layer, such as a calcareous or fine-grained surface crust, an algal or fungal mat, or an armor of gravel clasts. Marston (1986) has documented that deflation is a common result of maneuver activity on Fort Bliss, particularly on the bolson floor. If deflation progresses, blowout depressions can form small, internally drained basins that cause laminated, fine-grained sediments to accrete.

5.1.2.2 Depositional Eolian Landforms

As sand accumulates, relief features termed eolian bedforms develop. A three-stage size hierarchy of superimposed forms is generally recognized in classic sandy eolian bedforms (Wilson 1972; Summerfield 1991; Lancaster 1994). The smallest bedforms are termed ripples, which range in wavelength from approximately 1 cm to 5 m and in amplitude from 0.1 to 50 cm. Dunes represent the intermediate stage, with wavelengths of 50 to 300 m and heights of 5 to 30 m. Megadunes or draas represent the largest class, with heights of up to 400 m and wavelengths of up to 4 km. No megadunes occur on Fort Bliss; for this reason, the following discussion is limited to ripples and dunes.

Ripples are the smallest type of eolian bedform. They typically exhibit asymmetric profiles, with relatively gently inclined (8° to 10°), slightly convex slopes on the stoss side and steeper (20° to 30°), straight to gently concave slopes on the lee side. Wind ripples develop perpendicular to the vector of transporting winds, and always show a concentration of relatively coarse, resistant grains near the crest. The size of equilibrium ripples appears to be almost entirely a function of particle size and sorting with larger clasts forming larger ripples, while ripple wavelength represents a balance between sediment size and sorting and wind speed with higher winds resulting in longer wavelengths. Originally, Bagnold (1941) hypothesized that the mean length of the saltation path governed the wavelength of ripple formation, but subsequent investigators (e.g., Sharp 1963; Anderson 1987) have demonstrated that it is the mean distance of grain impact movements (reptations) rather than saltation hops that govern the spacing of wind ripples. As ripples are established, the low angle of incident saltating grains couples with the relatively steep lee face of ripples to create a "shadow" behind each ripple where grain impacts do not occur, and deposition and erosion are concentrated on the stoss faces.

Ripples migrate downwind because sand tends to be deposited on the upper lee face, just beyond the ripple crest. This increases the length and height of the stoss face and oversteepens the lee face. As the inclination of the lee face exceeds a critical value, termed the angle of repose, the crest of the ripple collapses, and sediments slide down the lee face in a process termed avalanching, forming sheets termed foreset laminae (Reineck and Singh 1980). These laminae develop a slightly gentler angle, termed the angle of rest (Carrigy 1970), that represents the angle at which the sediments stabilize. These angles vary slightly with grain size, shape, and moisture conditions, but the angle of repose is approximately 35° in most eolian sands, while the angle of rest is roughly 31° to 32° (Carrigy 1970; Reineck and Singh 1980). Because avalanching is typically an intermittent process except in conditions of very high sediment supply, finer-grained laminae deposited from suspension



Figure 15 Detail of a Blowout Depression Associated with a Road on Otero Mesa Containing a Lag of Ceramics and Chipped Stone. No artifacts are apparent on surrounding undeformed surface, suggesting that they are buried by eolian deposits.

frequently alternate with coarser-grained avalanche laminae in ripple foresets.

While a great number of dune forms are known, most dunes can be classified as variant on a few basic forms. Most sedimentology focuses on a class of dunes, termed free dunes (Summerfield

1991), that develop spontaneously in unrestricted environments as a result of variations in sediment supply, sediment character, wind speed, and wind direction. Major types of free dunes include linear (or longitudinal) dunes, transverse dunes, barchan dunes, star dunes, reversing dunes, and dome dunes. Illustrations of the major classes of free dunes are common in geomorphology texts (e.g., Chorley et al. 1984; Summerfield 1994). A second major class, termed impeded dunes, subsumes bedforms influenced by local topography and vegetation as well as sediment supply and character, wind direction, and speed (Summerfield 1991). Major classes of impeded dunes include parabolic dunes, coppice dunes, lee dunes, climbing dunes, falling dunes, echo dunes, and lunettes. The major distinction between free and impeded dunes is that free dunes can actively migrate across the landscape, whereas impeded dunes are restricted by the obstacle with which they are associated; while sediment can usually freely enter and leave impeded dunes, the dune itself is not subject to migration.

Like ripples, free dunes typically have a gentler stoss face where erosion is facilitated, and a steeper lee face where deposition predominates. The stoss face of dunes is typically mantled with superimposed ripples that are the result of the downwind migration of sediment over the dune. As in ripples, downwind migration tends to oversteepen the lee face of the dune, resulting in periodic avalanching down the lee face as the angle of repose is exceeded. Typically, only a part of the lee face will avalanche at any particular time, resulting in thin, interlocking lobes of avalanche deposits that are often partially reworked by turbulent eddies in the lee of the dune. In this manner, the bedform migrates downwind.

Transverse dunes represent elongated dunes oriented perpendicular to the prevailing winds, and thus represent a larger analog to ripples. Straight-crested transverse dunes are very rare; typically, microtopographic variations stimulate the development of heliocoidal flow vortices that result in a sinuous ridge crest termed barchanoid ridges. In conditions of moderately high to high sediment

supply, closely spaced barchanoid ridges result in a distinctive "fish scale" pattern of bedforms termed *aklè* dunes.

If sand supply is decreased, the same processes result in the formation of individual barchan dunes, which are characterized by a crescentic form with a slipface along the concave portion and "horns" that point downwind. Barchans typically occur as isolated or widely spaced bedforms, but can grow to considerable size.

Dome dunes represent mounded accumulations of sand that lack obvious slipfaces, and are characteristic of areas with relatively high sediment supplies. At White Sands, dome dunes are developed closest to the sediment source, where the influx of sediment is greatest (McKee 1966). Reversing dunes arise in areas with opposed winds, and are characterized by slipfaces that alternately form and are destroyed on opposite sides of the bedform. Star dunes represent complex forms that result from strongly alternating wind directions.

Linear (or longitudinal) dunes, including sinuous seif dunes, represent elongated, crested sand bodies oriented roughly parallel to the prevailing wind direction. They are a form of reversing dune, in that they have slip faces that alternately form on either side of the dune, resulting in very complex internal stratigraphy. Linear dunes typically do not migrate laterally; rather they expand downwind and are cannibalized upwind. Older models of linear dune formation (e.g., Folk 1970; Glennie 1970; Wilson 1972) propose that they form when opposing heliocoidal (corkscrew) vortices are established along the line of air flow, sweeping sand from the interdunal areas to the dunes. More recent models (e.g., Greeley and Iversen 1985; Fryberger et al. 1979; Lancaster 1994) suggest that longitudinal dunes probably result from unopposed, bidirectional winds (usually from the same quadrant) that result in a relatively constant vector of net sand movement; while heliocoidal flow patterns can sometimes be observed in such dune fields (Tseo 1990), it is probably a result of the influence of tall, linear dunes on air flow patterns,

rather than a spontaneous phenomenon responsible for their formation.

At present, no active free dune fields occur in the boundary of Fort Bliss. However, some relict, partially stabilized free dune forms (including transverse and barchan dune fields) have been noted within the reservation boundary (Budd et al. 1979), and extensive dune fields are preserved farther north in the Tularosa Basin at White Sands (McKee 1966; McKee and Moiola 1975). McKee has demonstrated that these gypsum dunes reflect essentially unidirectional, southwesterly winds, and exhibit a progression of forms (domed, transverse, barchan, parabolic) with increasing distance from the sediment source, implying that the major control on dune form is sediment supply. Although the sediments comprising dunes on Fort Bliss are dominantly siliceous rather than evaporitic, the relict dunes of Fort Bliss are the product of similar wind regimes, and should reflect similar erosional and transport processes and depositional morphologies. However, because gypsum dunes tend to become consolidated and ultimately destroyed by wetting, the distance that they will travel is somewhat reduced.

While free dunes are scarce, impeded dunes are ubiquitous on many parts of Fort Bliss. Impeded dunes represent the interaction between eolian processes and other elements of the landscape, such as vegetation or topographic features, and thus do not migrate freely across the landscape. The single most common type of dune on Fort Bliss is the coppice dune, which number in the tens of thousands on the bolson floor (Figure 16). Coppice dunes (also termed shrub-coppice dunes (Melton 1940) and coppice mounds in North America, and nebkha and dikaka in North Africa and the Arabian peninsula [Glennie and Evamy 1968]) consist of small mounds of eolian material stabilized around desert shrubs. On Fort Bliss, coppice dunes are typically associated with mesquite (*Prosopis glandulosa*) on the lower fans and bolson floor, and can attain heights of several meters.

Parabolic dunes are crescentic dunes that face the opposite direction from barchans (i.e., with the horns pointing upwind). They typically represent dunes fringing the downwind side of blowouts, but can migrate considerable distances downwind, leaving long trailing "arms" partially stabilized by vegetation. At White Sands, McKee (1966) has demonstrated that parabolic dunes are typical of the most distal, sediment-starved areas of the dunefield, where vegetation can best become established.

Fore dunes and lee dunes represent sand accumulations formed in front of and behind obstacles, respectively. These obstacles interrupt wind flow, decreasing velocity and increasing turbulence, and causing a drop in competence that results in sediment deposition. Almost any obstacle can stimulate deposition of fore and lee dunes, including vegetation, topographic irregularities, and cultural features. Fencelines, in particular, are frequently the site of considerable deposition in susceptible areas. In addition, fore and lee dunes can develop in association with other dunes, and are a common secondary component of the large coppice dune fields on Fort Bliss.

Climbing and falling dunes represent dunes associated with a topographic obstacle, such as a hill or entrenched arroyo. Climbing dunes represent sand moving upslope on the downwind side of the obstacle (Figure 17), while falling dunes represent sand moving downslope off the lee side of the obstacle. If the topographic obstacle is large, extensive, and relatively abrupt, echo dunes can develop at distance from the scarp base. In this situation, dune development is separated from the scarp by a large roller vortex, resulting in a dune that stands away from but parallels the scarp.

Lunettes are dunes associated with playa lakes. Desiccation and salt crystal growth in the playa pans can lead to cracking and subsequent deflation of the fine-grained material in the playa, which frequently results in accumulation of curved lunette dunes on the lee side of the playa. Because the playa sediments are typically silt and clay-sized particles, this erosion typically involves sand-sized

aggregates of finer particles. Subsequent wetting of these aggregates tends to cause them to break down and meld, forming relatively cohesive landforms termed clay dunes. Because these features are composed of cohesive sediments, they do not behave like sand dunes. Rather, they tend to accrete in the upwind direction and are not prone to migrate downwind. For this reason, the steeper face tends to occur on the upwind side, and can occasionally become significantly oversteepened by expansion of the playa.

Sand sheets and gozes represent two additional types of eolian deposits that lack dune morphology. Sand sheets consist of small to very large areas of laminated and planar bedded sands, occasionally containing interbedded pebbles. Gozes are large areas of gently undulatory sand developed in the presence of sparse desert vegetation, and frequently lack clear internal bedding because deposition is accomplished by complex vortices in the boundary layer caused by growing grass (Bagnold 1941; Reineck and Singh 1980). In general, development of sand sheets and gozes occurs when conditions for dune formation are unfavorable (Kocurek and Nielsen 1986). Dune formation may be inhibited by a number of factors, including a high regional water table, periodic flooding or sheetwash inundation, surface cementation, coarse-textured sediments, and vegetation cover. Sand sheets can also occur in interdune areas, as can finer-grained, laminated paludal sediments and truncated bases of previous dunes (McKee 1966).

The internal structure of eolian bedforms is a function of the processes of deposition, bedform size and morphology, rate of transport, sediment texture, and sediment supply (Reineck and Singh 1980). The majority of preserved bedding planes in most migrating dunes consist of crossbedded tangential foresets, which are curved surfaces that represent former positions of the lee face. If sediment influx exceeds sediment loss on the stoss face, then ripple migration up the stoss face results in thin, laminated, gently inclined beds on the stoss face; these beds are rarely preserved because subsequent migration typically destroys them.

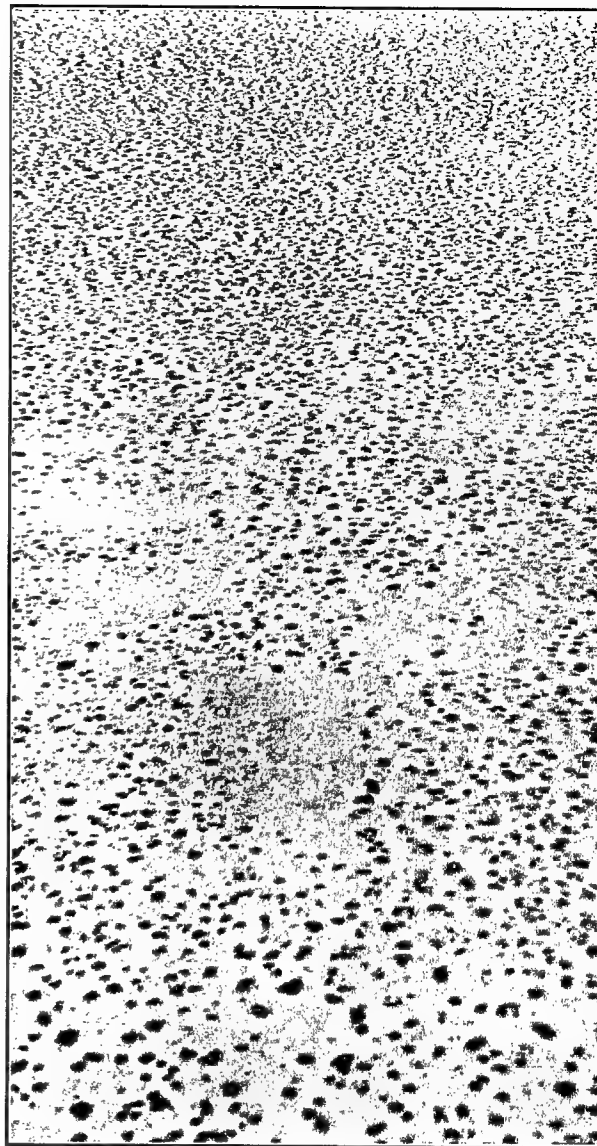


Figure 16 Oblique Aerial Photograph of the Bolson Floor, Illustrating the Character of Mesquite Coppice Dune Fields.

Bagnold (1941) terms these two types of beds encroachment deposits and accretion deposits, respectively. Finally, massive or laminated horizontal bedding can develop in interdune areas and on lower parts of the dune.

Bounding surfaces are planar or curved contacts between beds. A three-part hierarchy of bounding surfaces between bedforms is typically recognized



Figure 17 Large Climbing Dune Containing Archeological Strata Developed on the Margin of a Fan-channel Arroyo, McGregor Range.

(Brookfield 1977; Kocurek 1981). First order-bounding surfaces are extensive, relatively smooth, subhorizontal bedding contacts. They are generally interpreted as surfaces created by the migration of very large eolian bedforms. Second-order bounding surfaces separate two sets of crossbedded strata with different bedding directions and/or inclinations, and are indicative of superposed bedforms in a migrating dune field. Third-order bounding surfaces are divisions between subparallel packets of planar or ripple laminae within a coset of crossbeds, and are indicative of fluctuations in wind energy or direction in a single migrating bedform.

5.1.3 Paleoclimatic Implications of Eolian Deposits

As stated previously, eolian entrainment and transport requires several basic conditions: (1) wind of sufficient strength; (2) suitable sediments; and (3) a paucity of anchoring vegetation. It

follows that long-term climatic variation should have an effect on the magnitude of eolian activity, and evidence of episodic activity has been observed in a great many eolian environments around the world (Lancaster 1994). Although frequently true, it would be a mistake to assume that eolian activity will necessarily coincide with periods of maximum aridity. Temperature shifts, changes in the magnitude and character of prevailing winds, and shifts in the periodicity and timing of annual precipitation can also initiate or limit eolian activity (Lowe and Walker 1984). More importantly, changes in the amount of available sediment can also exert strong control (Tchakerian 1994). Although shifts between arid and humid climatic regimes should facilitate and inhibit eolian activity, respectively, smaller-scale shifts between slightly less arid and more arid conditions would not necessarily have the same effect; indeed, a shift to slightly moister conditions in an arid environment could result in increased eolian activity by increasing the delivery of

relatively high volumes of fresh, erodible sediment by alluvial systems. A linkage between eolian and alluvial processes is implied for Fort Bliss by Monger (1993e), who tentatively correlates eolian deposits in the basin with episodes of activity on the alluvial fans. Thus, initiation and abatement of eolian activity may be at least partly a secondary function of changes in alluvial fan activity, which are themselves linked to climate in a less than straightforward fashion (Bull 1991; see Section 5.2). In other words, the response of eolian systems to climatic shifts is apt to be complex, and is interrelated with dynamics of other geomorphic and biotic subsystems.

5.1.4 Geoarcheological Implications of Eolian Processes and Deposits

Eolian processes and deposits have a number of profound implications for the preservation and visibility of archeological sites. Many of these implications are so fundamental as to seem almost trite; nevertheless, they are frequently ignored in archeological investigations, and particularly in regional analyses of settlement distributions.

In general, the following seven implications pertain to archeological sites in eolian settings.

5.1.4.1 Eolian Setting Implication #1

If the archeological remains of interest are postdated by active eolian activity, then they are likely to be either deflated (if located in a locus of net erosion), buried by eolian sands (if located in a locus of eolian deposition), or both (Figure 18). Thus, the character and magnitude of eolian activity and the extent, depth, and morphology of eolian deposits condition the visibility and integrity of archeological sites that predate that activity. Moreover, because loci of eolian erosion and eolian deposition are typically closely related, deflation and collapse of previously existing archeological stratigraphy is likely in any situation where older, stratified deposits are present. Any artifacts in this general context, whether deflated or in situ, should typically rest on a higher-order

bounding surface (e.g., first or second-order) unless displaced by bioturbation.

An alternative model has recently been proposed by Burgett (1994). Burgett observes that artifacts in the Hueco Bolson are often recovered from the upper sand mantle in sediments that are generally considered historic in age, and argues that artifacts may float on top of or within accumulating packets of eolian sand. Although this proposal runs counter to the models of artifact behavior in eolian contexts presented previously and while there are some problems with the physical aspects of Burgett's model, a similar revolutionary hypothesis has recently been convincingly advanced for the formation of desert pavements (McFadden et al. 1987). The processes and timescales proposed by McFadden et al. are not precisely comparable, but the basic phenomenon of floating clasts is similar, and Burgett's proposal should not be dismissed out of hand. However, if the phenomenon identified by Burgett is real, and older artifacts are common in younger sand bodies on Fort Bliss, a viable physical mechanism remains to be proposed.

5.1.4.2 Eolian Setting Implication #2

If the occupation occurred at the same time that eolian deflation, transport, and deposition was ongoing, then archeological materials associated with that occupation will also probably be buried. These deposits too are subject to displacement by eolian processes. Because most artifacts exceed the size necessary for effective eolian transport, they are primarily subject to gravity-driven displacement as the sand around them is entrained and transported (see implication 5 below).

Barring displacement byurbation processes, artifacts deposited in a dune environment should rest on or between third-order bounding surfaces if the artifact is associated with the original bedform or if the surface aggrades sufficiently before passage of any subsequent bedforms. If, however, the eolian matrix is removed by deflation, the material should rest on higher-order (typically second order) bounding surfaces, and may be either exposed or buried. If sediment supply is

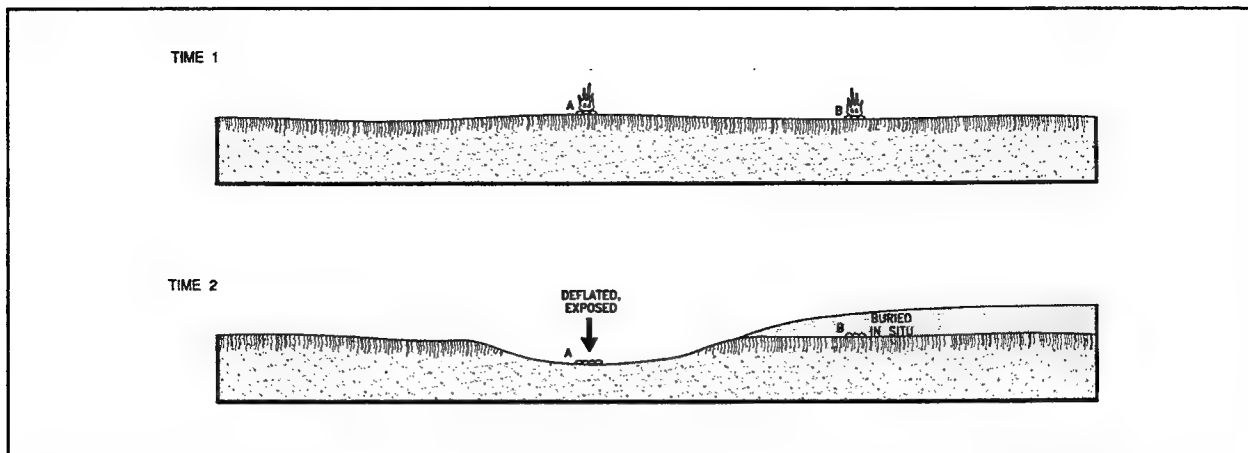


Figure 18 Generalized Model of the Effects of Subsequent Eolian Activity on Archeological Sites.

sparse, deflation is a virtual certainty, because the magnitude of erosion will outpace the rate of burial. However, even if the sediment supply is high and the surface is actively aggrading, artifacts deposited on higher parts of the landscape are still subject to deflation before burial (Figure 19).

5.1.4.3 Eolian Setting Implication #3

If the archeological remains of interest postdate all eolian activity (i.e., occur on bedforms stabilized by vegetation), then they should rest on top of eolian landforms and be visible on the surface unless buried by other, subsequent processes (e.g., sheet or rill erosion and deposition, rainsplash, soil creep).

5.1.4.4 Eolian Setting Implication #4

If the occupation occurred during a period of stability that was bracketed by episodes of increased eolian activity, then the artifacts should be associated with buried paleosols in the eolian complex. Because the resilience of desert epipedons is usually not great unless the surface is stabilized by vegetation, artifacts that occur in association with a preserved A horizon typically imply site formation during that period of stability. In this case, bioturbation associated with pedogenesis can be expected to have obliterated associated third-order bounding surfaces, should any have originally existed. If renewed eolian activity results in erosion, then the soil can be

expected to be deflated down to portions of the solum rendered more resistant by clay or carbonate accumulation. Any artifacts should rest on a second-order (or, occasionally, a first-order) bounding surface defined by this process of truncation (Figure 20). If the duration of pedogenesis was short, and the degree of alteration in the resultant soil was relatively low, all evidence of the soil could easily be destroyed by deflation, and the depositional setting could be indistinguishable from the previously described situations (i.e., Implications 1 and 2).

5.1.4.5 Eolian Setting Implication #5

In all cases, the spatial integrity of archeological materials interstratified in eolian contexts should be considered suspect. As several studies of the effect of eolian processes on archeological materials (e.g., Beckett 1980; Shelley and Nials 1983; Simms 1984; Wandsnider 1988) have shown, eolian processes are capable of laterally displacing artifacts on the surface, either directly in the traction load (either directly by wind action or, in the case of small artifacts like thinning flakes, by grain impacts) or through undermining of supporting strata, which stimulates gravity-driven movement. Wandsnider (1988) also identifies, but does not fully explain, a third mechanism she says is capable of moving artifacts:

"...transport artifacts indirectly (sizes unknown) by forming small obstruction dunes behind the

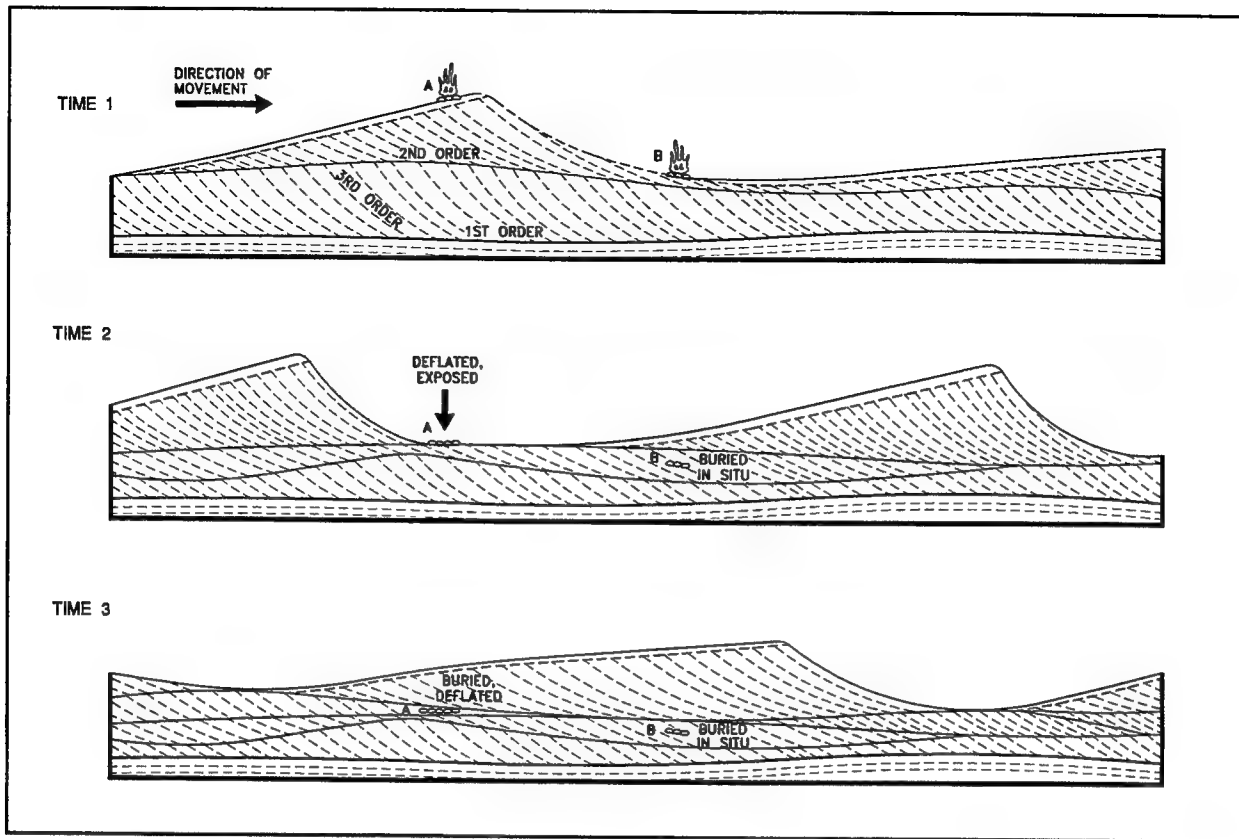


Figure 19 Generalized Model of the Effect of Dune Migration on Preservation of Archeological Sites Formed in an Active Eolian Environment.

artifact, which then "plow" the artifact along..."(1988:20).

It seems that Wandsnider envisions a process where a foredune formed on the windward side of an artifact expands or migrates downwind, pushing the artifact in front of it. Part of the considerable ambiguity of this proposed process concerns Wandsnider's use of the adjective "behind," which appears to refer to the upwind side of the artifact; while this location apparently describes position relative to the vector of travel, it is utterly confusing when used in the context of a discussion of eolian transport and deposition, where "behind" is synonymous with "downwind." However, no matter what the intended orientation of "behind," the proposed process is not viable. If the dune envisioned is a fore dune, then formation of the dune would cause flow separation and flow detachment around the obstacle, decreasing tractive force; although the dune might expand downwind,

burying the obstacle, it would not be capable of pushing the obstacle in front of it. If, instead, the bedform Wandsnider envisions is actually a lee dune, any movement of the object would be due to wind friction and would be inhibited, rather than facilitated, by a mound of sand on the lee side.

The ability of wind to displace surface artifacts is a function of many interrelated variables, including artifact size, shape, mass, and orientation; macro- and microtopographic setting; slope; vegetation character, density, and placement; surface roughness; and surface hardness or compaction. Clearly, displacement of individual artifacts within a scatter will vary as a function of these variables. Moreover, manmade artifacts are frequently more subject to transport than natural clasts because of their shape. While a natural clast is typically rounded by transport, and thus exhibits a small surface area to mass ratio, manufactured artifacts like lithic debitage and potsherds typically exhibit

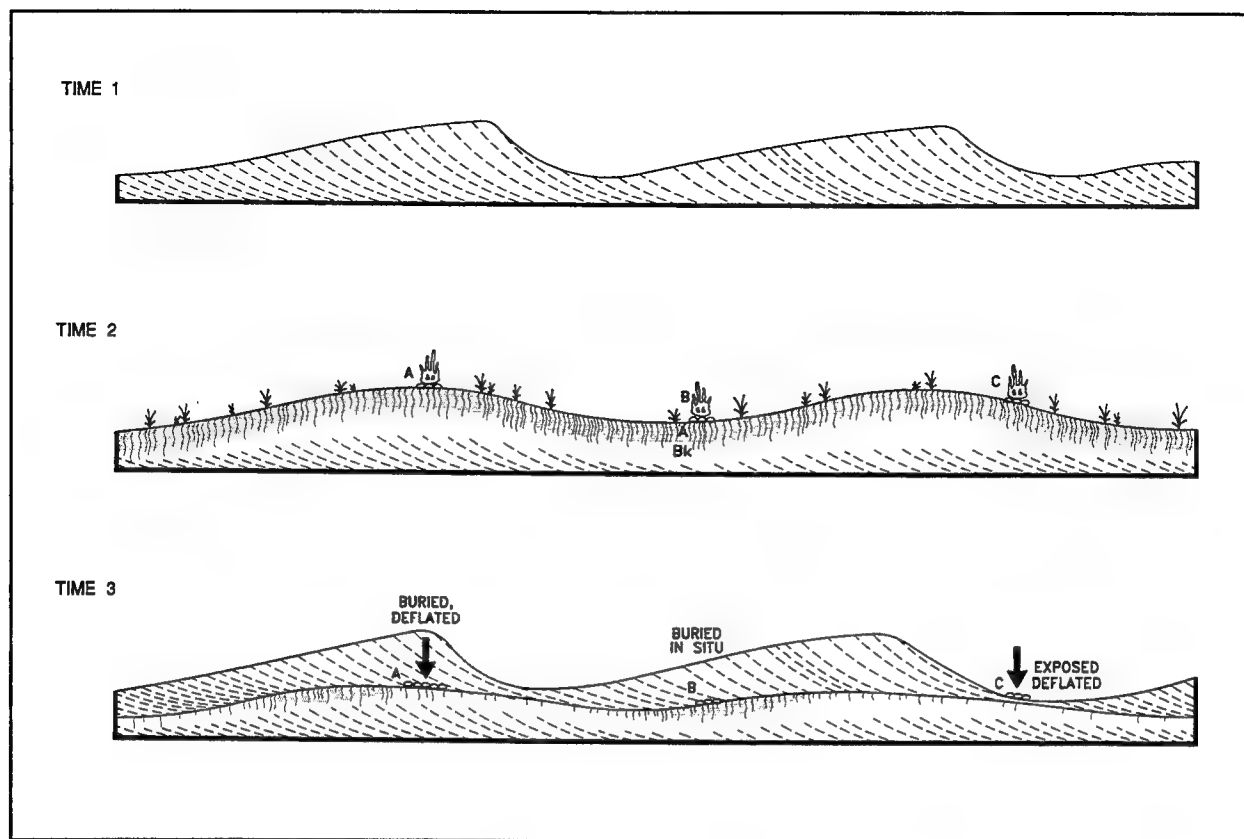


Figure 20 Generalized Model of the Effect of Renewed Eolian Activity on Archeological Sites Formed in a Stabilized Eolian Environment.

relatively large surface areas relative to their mass, and are thus much more susceptible to movement by gusts of wind.

As Shelley and Nials (1983) demonstrate, direct transport of relatively large objects can occur (e.g., potsherds can be displaced upslope for short distances). However, it is fallacious to extrapolate long-term estimates of artifact movement from short-term data. One reason for this is that artifacts deposited on an eolian surface appear to undergo an initial "settling in" period of a few months to a few years, during which time they are in strong disequilibrium with the environment, and thus most prone to movement (Wandsnider 1988). More importantly, long-term artifact behavior cannot be extrapolated from short-term observation because the absolute distance that a given artifact will move is constrained by local topography and depositional setting. For example, while it is not unreasonable to expect a meter or more of

movement by an individual sherd in a blowout depression during a short period of observation (or even a single strong windstorm), it is very unlikely that such an artifact will ever "climb out" of the blowout, which would be required for long-distance displacement.

While direct transport can be a significant factor, artifacts deposited in a dune system will probably be more strongly impacted by gravity-driven movements as the sand around them is exhumed by eolian processes. In a typical migrating dune, it can be expected that heavy artifacts deposited on the stoss face will gradually tend to migrate downslope (upwind) as surrounding sands on the windward face of the dune are progressively eroded. While artifacts deposited on the steeper lee slope can also move downslope, they are much more prone to rapid burial; note that these artifacts too can emerge on the stoss face as the dune migrates laterally. Once an artifact reaches the

interdune area, there is little impetus for movement provided by gravity and most movement should be a function of direct traction transport. The movement of artifacts in sand sheets should also be primarily a function of direct traction transport due to the lack of relief, although the formation of deflation hollows can provide local sloping surfaces that facilitate gravity movements.

Given that the potential for displacement of artifacts is high in an eolian environment, lack of integrity should typically be assumed unless evidence that the material is *in situ* exists. Such evidence could include strong patterning in artifacts of different sizes in a manner that would not easily result from natural processes (e.g., a half-moon scatter of lithic debitage surrounding a chipping station) or discovery of intact features. Even so, evidence that a particular portion of a site is undeflated should not be taken as evidence that the entire site is unaffected.

5.1.4.6 Eolian Setting Implication #6

In most cases, and particularly where archeological materials rest on higher-order bounding surfaces, the stratigraphic integrity of recovered materials must also be considered suspect. Deflation is universally recognized as a significant process in eolian environments. Direct deflation of an archeological assemblage resting on or stratified in an eolian dune can result in collapse of the strata as the heavy artifacts are left behind as a lag. Typically, this process is accompanied by lateral dispersion because the artifacts will tend to anchor the sands upon which they rest, causing surrounding sands to erode faster, and creating a temporary topographic high from which the artifacts can roll or slide (Figure 21).

However, if artifacts are displaced by lateral expansion of a blowout, it is possible that they could roll or slide down the inclined margin of the deflation hollow and come to rest on or in a thin sheet of sand mantling the floor of the blowout (Figure 22). Thus, dispersed materials can also become concentrated into false clusters. This type of process is also likely to result in size sorting of

the remains because smaller artifacts are likely to move farther and more readily than larger, heavier artifacts.

Finally, it is possible for this process to displace an archeological feature vertically without significant lateral dispersion. Thus, a cluster of hearth stones could theoretically be deflated significantly without destroying the spatial relationships that allow identification of the cluster as a hearth. However, such a feature should be completely devoid of charcoal and/or stained or oxidized sand. While the presence of charcoal should suggest relative integrity, because an *in situ* feature that has not undergone significant deflation could also lack this evidence given many different conditions and burial histories, the lack of charcoal and staining cannot be considered firm evidence for deflation.

5.1.4.7 Eolian Setting Implication #7

In eolian environments where loci of deposition alternate with loci of erosion, visibility of the archeological record, and particularly the spatial patterning of sites, will be conditioned not only by human activity but also by the size and frequency of erosional "windows" through the sand mantle. Thus, considerations of intersite patterning are not viable unless the bias imposed by differences in the potential for site visibility are accounted for.

5.1.5 Eolian Record in the Fort Bliss Region

The eolian record on Fort Bliss proper (i.e., exclusive of McGregor Range) has been examined by Monger (1993b; 1993e), who is reportedly conducting additional investigations within the post boundary. The other major source drawn on for this summary is the work done on the western flank of the Jarilla Mountains immediately north of Fort Bliss in White Sands Missile Range (e.g., Blair et al. 1990a; 1990b; Doleman and Swift 1991). Collectively, these studies provide a good first approximation of the eolian record preserved on the basin floor, and serve as the basis of this synthesis. Although briefly noted by Piggott (1977), little information exists for eolian deposits elsewhere on the post, and on Otero Mesa in

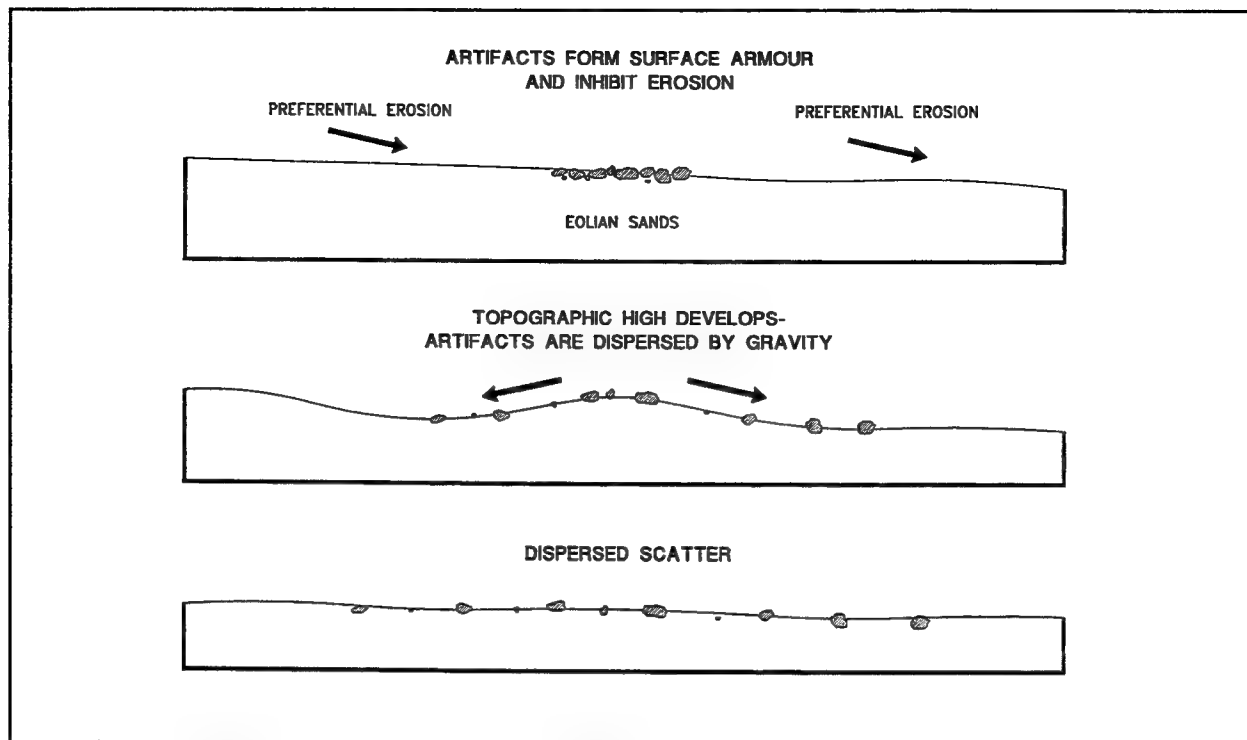


Figure 21 Generalized Model of Artifact Dispersion by Eolian Activity.

particular. Nevertheless, it is likely that the same types of controls operating on the basin floor were also operating in the higher portions of the base, and thus resulted in a broadly similar stratigraphic sequence; however, because the sediment supply was probably much more limited on Otero Mesa, the thickness of eolian deposits is liable to be lower, and erosional truncation may be more common. This tentative conclusion, however, requires further study.

Monger (1993e) tentatively identifies four episodes of Holocene eolian activity on the installation, which he equates with episodes of fan and arroyo activity previously identified in the Desert Project study area on the opposite side of the Organ Mountains (Gile and Grossman 1979; Gile et al. 1981). A broadly similar sequence, albeit with less resolution during the Holocene and extending farther back into the Pleistocene, is identified at White Sands Missile Range (Blair et al. 1990a; 1990b). These episodes of eolian activity resulted in deposits that have experienced different degrees of pedogenesis, and thus can be correlated using

soil development criteria. Table 11 correlates the sequences and diagnostic features proposed by Monger (1993a) and Blair et al. (1990a; 1990b).

With the exception of the historic sands, each of these eolian units appears to have accumulated over broad areas as relatively low-relief sand sheets with some larger eolian ridges and mounds, but few large, active dunes. Transport appears to have occurred primarily through ripple drift and grain fall processes, probably in the presence of moderate amounts of vegetation (Blair et al. 1990b). For this reason, the stratigraphic units can frequently be found stacked in individual profiles. However, because in each case broad to relatively closely spaced areas of deposition alternate with comparable areas of erosion, all units do not occur in every profile, and the thickness of individual units varies considerably. Overall thickness of the Late Pleistocene and Holocene units in the basins is unknown, but investigated parts of the sequence range between 0 and approximately 3 m thick, although in most areas on the basin floor depth to calcrete is less than 1.5 m (Monger 1993e; Blair et

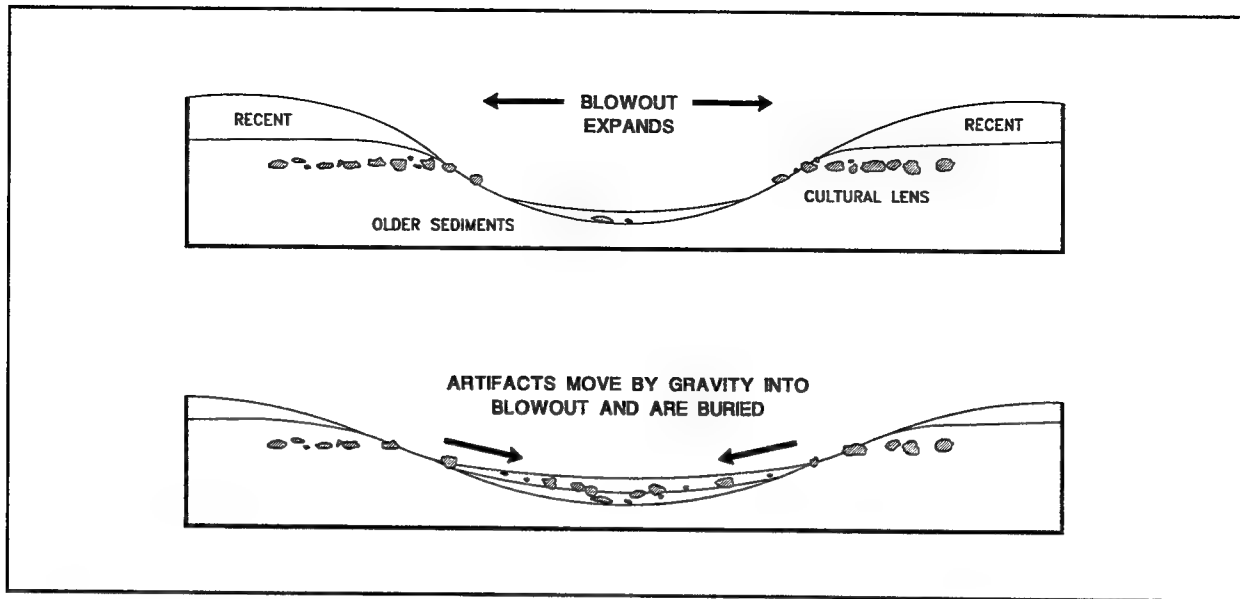


Figure 22 Generalized Model of Artifact Concentration by Eolian Activity.

al. 1990b). As Table 11 illustrates, primary eolian stratification is typically only preserved in the most recent dunes. This lack of stratification is consistent with sand sheet deposition (Kocurek and Nielsen 1986; Fryberger et al. 1979) because extensive bioturbation frequently accompanies eolian aggradation in a vegetated environment (Pye 1983).

Both Monger (1993e) and Blair et al. (1990b) tentatively relate the formation of these eolian sand sheets with relatively arid intervals. Presumably, eolian activity was closely linked to increased activity on the fan-piedmont, resulting in the delivery of increased amounts of erodible sediments and a decrease in eolian-inhibiting vegetation on the basin floor. Conversely, cessation of eolian activity would have coincided with increasing slope stability, decreasing sediment delivery, and more pervasive vegetation cover on the basin floor and on the mountain slopes. The sole exception is the modern environment, which is interpreted as the irreversible consequence of overgrazing on a fragile, marginal grassland (York and Dick-Peddie 1969; Buffington and Herbel 1965).

Although this model is tenable, further work is needed to effectively relate the landscape response

to a climatic stimulus. As outlined in Chapter 2.0, most paleoclimatic work from the region paints a unidirectional picture of decreasing effective moisture throughout the Holocene. Although the initiation of Organ/Q3 deposition around 7000 to 7300 BP does appear to follow the crossing of an environmental threshold about 8000 BP that marked the initial appearance of many of the modern Chihuahuan Desert species, much of the extant paleoenvironmental data suggests that grasslands persisted until around 4000 BP, when they were superseded by desert scrub (Van Devender 1990). Interestingly, no extant data suggests a change in eolian activity coincident with this shift in vegetation. Pollen data described by Freeman (1972) from the Gardner Springs site in the Desert Project study area suggests that grasses may have been replaced by scrub in the early Middle Holocene, only to flourish again for a short time during the early Late Holocene (approximately 4500 to 3500 BP) before being replaced again by desert scrub. Once again, no clear geomorphic response to these apparent vegetation shifts are preserved in the stratigraphic record. Conversely, apart from the stratigraphic evidence, there is no real local corroboration for climatic forcing as a mechanism in the transition between Organ I-Organ II and Organ II-Organ III deposition at 2200 BP and 1000 BP, respectively.

Table 11 Correlation of Eolian Deposits on Fort Bliss and White Sands Missile Range.

| EOLIAN STRATIGRAPHY, FORT BLISS Monger 1993 | | | WHITE SANDS MISSILE RANGE, GENERALIZED SOIL STRATIGRAPHY Blair et al. 1990a; 1990b | | |
|--|---|-----------------------|---|---|-------------------|
| Unit | Diagnostic Feature | Tentative Age | Unit | Diagnostic Feature | Tentative Age |
| Historic Blowsand | stratified eolian sediments | 1850 A. D. to present | Q4 | loose single grain structure; primary sedimentary structures partially disrupted by bioturbation; weak, local vesicular A horizons; occasional faint Stage I filaments | >100 BP |
| Organ III | No eolian strata, no carbonate filaments | 100 to 1100 BP | Q3 | A-Bw-C or A-Bk-C profile (often truncated); soft to slightly hard dry consistence; single grain or weak to moderate subangular blocky structure; | 100-7300 BP |
| Organ II | Faint Stage I filaments | 1100 to 2100 BP | | Stage I carbonate morphology or slight reddening and clay enrichment | |
| Organ I | Prominent Stage I filaments, commonly 5YR hues, faint clay skins | 2100 to 7000 BP | | | |
| Isaack's Ranch | no eolian deposits of this age described; however, lag carbonate nodules indicating deflation of older strata are present | >7000 BP | Q2 | Btk, Bk, or Btk-Bk profile; A horizon truncated; hard to very hard dry consistence; moderate angular-subangular blocky structure; Stage II carbonate morphology; distinct reddening and illuvial clay | 9400-15,000 BP |
| Jornada II | no eolian deposits of this age described | | Q1 | truncated; Btk-K-Bk profile; Stage III to Stage IV carbonate morphology | 50,000-250,000 BP |

However, there is clear geomorphic evidence of a sudden shift in climate around 1000 BP on the southern Plains (Hall 1990a), suggesting that the Organ II-Organ III transition may indeed have a climatic cause not reflected in the local biotic record.

One of the problems with Monger's (1993e) model is that the subdivision of the Organ eolian sequence into Organ I-III phases does not include the stable periods necessary for the formation of soils that define the units. In reality, this is a problem in resolution; the bulk of eolian activity probably would have occurred relatively early in the bracketing timescales, while relative stability, and concomitant soil development, would have dominated during the latter part of each episode. In addition, although the sequence is defined only at a temporal scale, there is good reason to expect spatial variability in the location of active eolian environments in the basin, which introduces additional complexity. For these reasons, there is a strong need for additional data to refine the eolian sequence to reflect periods of stability and instability in a spatiotemporal framework.

Monger (1993c) has identified and mapped several broad categories of eolian alteration within the Fort Bliss maneuver areas. These broad categories include a variety of subcategories, resulting in seven distinct mapping units:

- 1a. large dunes (generally more than 1 m in relief) with collapsed interdune strata;
- 1b. small dunes (generally less than 1 m in relief) with collapsed interdune strata;
- 1c. deflated nondune areas;
- 2a. large dunes with interdune sheet deposits;
- 2b. small dunes with interdune sheet deposits;
3. depositional areas comprised of sand sheet deposits; and
4. areas where soil strata are modified little by wind.

In Figure 23, mapping units 1a, 1b, and 1c are defined on the basis of dune size and the presence of a surficial lag of carbonate nodules in the interdune areas. This nodular lag is equated with Isaack's Ranch soil development, and provides a clear indication that Holocene depositional units are not preserved in the interdune areas. Mapping units 2a and 2b are also characterized by dunes,

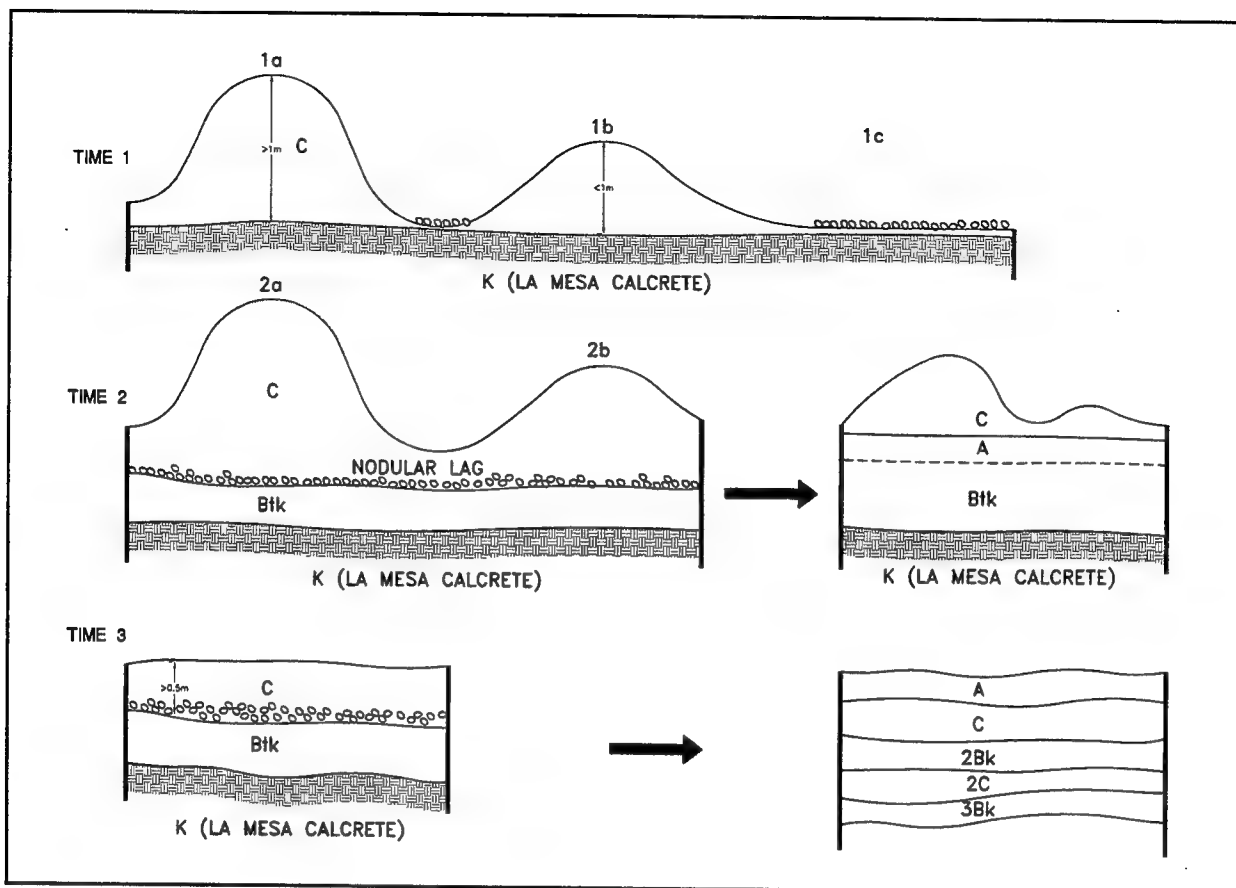


Figure 23 Illustration of Eolian Alteration Units. After Monger 1993c.

but lack the nodular lag in the interdunal swales, indicating that Holocene eolian deposits (e.g., Organ and/or Isaack's Ranch) may be preserved at depth. Mapping unit 3 consists of sand sheet deposits that exhibit no surficial lag of carbonate nodules and no dunes; they also may contain preserved archeological strata. Finally, mapping unit 4 consists of areas that do not exhibit evidence of substantial eolian truncation or additions, such as fan and playa surfaces.

The profiles represented in Figure 23 represent only a few of the possible profiles underlying Monger's four mapping units. The character of soil profiles developed in eolian deposits will reflect the net result of the magnitude of localized erosional and depositional episodes through the late Quaternary. Preliminary work in the maneuver areas (Monger 1993a) and elsewhere in the bolson (Abbott 1995) demonstrate that the thickness and

geometry of the Isaack's Ranch unit and the various Organ units can vary considerably over short distances depending on the patterning of blowouts that develops on each successive paleosurface as it is erosionally truncated during subsequent active episodes. Figure 24 schematically illustrates lateral variability in depositional units documented at a series of sites in the northern Hueco Bolson, just southeast of Fort Bliss (Abbott 1995); similar relationships are suggested at the Tobin Wells and McNew Tank Pipeline localities on Fort Bliss (Monger 1993e). Although these studies provide only a few examples, they do demonstrate that the internal stratigraphy of the eolian deposits can be very complex and exhibit strong lateral variability over relatively short distances.

In particular, there is strong evidence (Gile 1966a; Abbott 1995) that A horizons of the last episode of

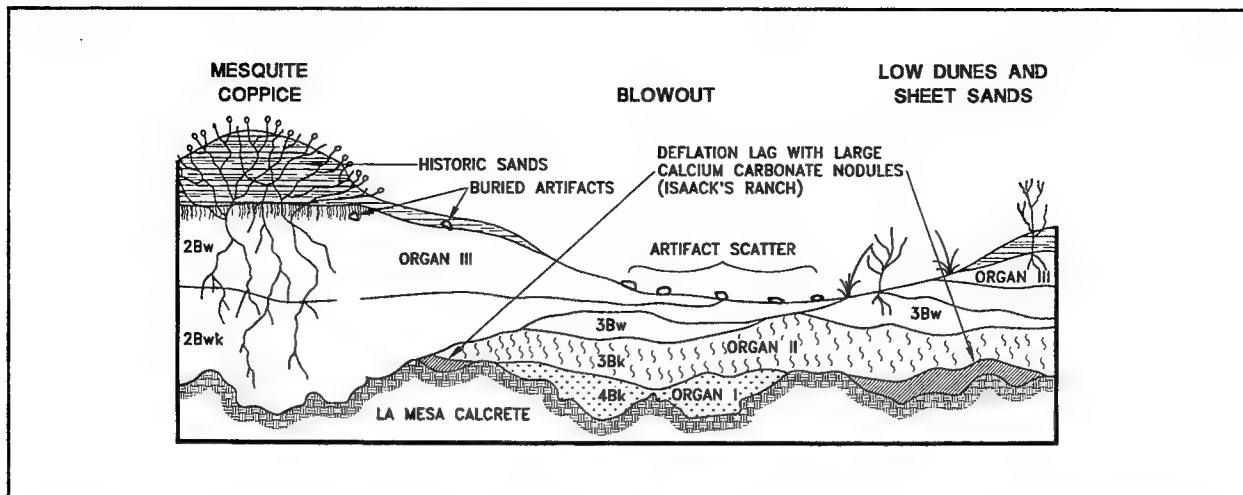


Figure 24 Schematic Illustration of Stratigraphic Variability Observed at a Single Archeological Site in the Northern Hueco Bolson. After Abbott 1995.

landscape stability are frequently preserved in coppice dunes at elevations higher than the modern interdunal areas (see Section 5.5). This is not surprising, given the model for formation of the coppice fields. Presumably, the coppice dunes developed as a result of historic overgrazing, which resulted in both the destruction of the fragile grassland ecosystem and the wide distribution of mesquite beans in the dung of grazing stock. As the grass cover disappeared, eolian erosion began to occur. However, pockets of sand were rapidly trapped by young mesquites, armoring portions of the surface. As this process progressed, relief in the coppice dune fields increased as the interdunes were increasingly deflated and the mesquite plants grew, trapping more and more sand.

Four basic geoarcheological implications that pertain to the eolian deposits on Fort Bliss can be derived from Monger's (1993e) model.

First, significant eolian activity has occurred during the archeologically relevant time span within the boundary of Fort Bliss. Therefore, it follows that much of the archeological record is concealed by more recent eolian deposits, and the pattern of sites discovered by pedestrian survey and the apparent size of those sites, are a combined function of the actual distribution and size of sites and the pattern of potential visibility provided by the patterning of

eolian deposits on the post. In general, sites in mapping units 1a and 1b should be visible in interdunal areas, and thus apparent sizes should be a combined function of the actual size of the scatter and the distribution of erosional "windows"; sites in mapping unit 1c should be wholly visible; sites in mapping unit 3 should be buried and undetectable from surface survey; and sites in mapping unit 2 should be either limited by erosional windows (if the deflation hollows are deep enough to expose the cultural strata and fresh sands are not present in the interdunes) or undetectable (if the deflation hollows are not as deep as the cultural strata or fresh sheet sands are present in the interdunes). The potential visibility of sites in mapping unit 4 is unrelated to eolian processes, and should be evaluated using other appropriate criteria.

Second, buried cultural strata could potentially be preserved anywhere in mapping units 2a, 2b, and 3, necessitating subsurface testing to determine their presence and distribution. Because the internal stratigraphy of the eolian cover can vary considerably within a short distance, this testing should be relatively intensive. In mapping units 1a and 1b, the potential for preserved cultural strata should typically be limited to the dunes; the interdune areas should have poor potential for any semblance of stratigraphic integrity. Similarly,

mapping unit 1c should have poor subsurface potential and would not require testing. Once again, the potential of areas included in mapping unit 4 would have to be evaluated on the basis of other criteria.

Third, horizontal patterning of exposed artifacts in all mapping units should be carefully and critically evaluated for evidence of disturbance, and should probably be considered to lack culturally significant patterns unless evidence to the contrary is apparent. In particular, the artifacts in mapping units 1a, 1b, 2a, and 2b should be examined for size patterning or other evidence of sorting, and clustering of artifacts in interdunal areas should be examined critically before assigning any behavioral relevance to the pattern. Similarly, artifact scatters in mapping unit 1c should be examined carefully for evidence of possible dispersion or concentration.

Fourth, vertical patterning of materials in section should also be carefully evaluated for evidence of deflation and bioturbation. Buried materials associated with major bounding unconformities between units should be examined with particular care. In all cases, a concentration on evidence for collapse of multiple primary strata into secondary palimpsest assemblages, which would strongly limit the potential utility of the recovered assemblage, should be emphasized.

In summary, the potential visibility and integrity of sites in the eolian environment on Fort Bliss varies widely. The mapping of eolian alteration strata by Monger (1993c) provides a powerful tool to adjust for geomorphic bias in the distribution of sites detected by pedestrian survey. Any examination of intersite patterning on the bolson floor that ignores this bias will yield spurious data. At the intrasite level, appreciation of the potential effects of eolian processes on surficial artifact patterns must be carefully considered. Even in the case of buried components, it is likely that the same types of disturbance processes described above would have affected the assemblage before burial, and the likelihood for any cultural component to be preserved in "pristine" context is extremely remote.

Thus, evaluation of NRHP eligibility will require not only an evaluation of the extent of disturbance, but also a judgment of the degree to which that disturbance compromises the research potential of the site. Clearly, given the character of the environment, the integrity of a site cannot be the sole criterion by which significance is evaluated, because such a strategy would eliminate large, contiguous tracts by default. Nevertheless, the degree of integrity is clearly one very important consideration in the evaluation of a site overall, and certain conditions where integrity is compromised, such as situations where multiple discrete strata are collapsed into a single inseparable palimpsest, should weigh heavily against the determination of significance.

5.1.6 Research Questions

A number of geoarcheological research questions can be generated to address sites in the eolian environment on Fort Bliss. These questions can be subdivided into two classes: site-specific questions, which apply to one particular locality; and regional questions, which apply to larger areas or to the post as a whole.

5.1.6.1 Site-Specific Research Questions

The following questions apply to sites in the eolian environments on the base. They are all intimately related and represent the suite of questions that should be posed routinely at each eolian site investigated. Because the data needs for each of the questions are relatively simple and largely identical, the questions are all posed first, followed by a single identification of data needs and an integrated discussion.

- 5-1 What is the character and timing of the eolian deposition? How many cycles of deposition are preserved?
- 5-2 What is the timing of erosional episodes?
- 5-3 What is the timing of episodes of site stability?

-
- 5-4 What is the character of depositional architecture at the site?
 - 5-5 Are stratified components present, or is all material at or just beneath the surface?
 - 5-6 What is the stratigraphic context of archeological remains? How old are the encasing deposits?
 - 5-7 Do the sealed components appear to be in primary or secondary context?
 - 5-8 What evidence is there for horizontal disturbance? Vertical disturbance?
 - 5-9 Are the archeological deposits contained within or stratified between depositional units? What order of bounding surface are they associated with, if any?
 - 5-10 What is the likelihood that the archeological remains represent more than one time period?
 - 5-11 What types and degrees of postdepositional modification of deposits are apparent?
 - 5-12 What is the source of the eolian sands? Does it appear to be locally derived, or has it been transported in considerable distances?
 - 5-13 What was the topography like at the time of deposition? Were dunes developed, or was the environment a sand sheet? If dunes were present, in what part of the environment was the site developed (e.g., stoss face, lee face, interdune)?
 - 5-14 To what extent is archeological visibility inhibited by eolian sands?
 - 5-15 What does geometry and bedding suggest about the depositional environment?

- 5-16 Is there any evidence that the artifacts have "floated" up through the profile during deposition? If so, what are the characteristics of those artifacts? Do all artifacts appear to move equally, or are there size/shape/mass relationships apparent?

Data needs: Eolian stratigraphic context, extensive (mechanical) exposure of site stratigraphy; absolute and relative chronometric information.

These questions should all be addressed with the same types of data. The single most important requirement is extensive exposure; few of the above questions can be addressed with only one or two trenches. While few of the questions can be conclusively answered with even a moderate level of subsurface effort, such an expenditure will allow for strong tentative conclusions that are not possible without subsurface examination. In fact, it can be argued that because geomorphic processes impose such a strong filter on archeological visibility, any type of reasonable site assessment in the eolian landscapes are impossible without subsurface testing. It follows that if individual site assessments are impossible, regional interpretations of settlement and subsistence built on site distributions are also impossible, and any such models based on current pedestrian survey data from this environment represent models based on biased information and cannot be considered tenable.

5.1.6.2 Regional Eolian Research Questions

The following questions pertain to regional geoarcheological and geomorphological trends apparent in the eolian record. They represent the longer-term goal of understanding the linkages between eolian activity and archeology in the study area.

- 5-17 What is the temporal sequence of eolian deposition and stability in the Tularosa/Hueco basin?
-

- 5-18 Can basin-wide episodes of landscape stability be identified, or are episodes of stability and instability localized? In other words, what is the spatial variability in this temporal sequence?
- 5-19 Does the thickness of eolian deposits vary in a systematic manner? How is the sequence related to sequences on the margins of the bolson?
- 5-20 Are the chronometric ages obtained from the sites consistent with Monger's (1993a) sequence?
- 5-21 To what extent is the site database spatially biased by the variable eolian cover? Where are buried sites most likely to occur?
- 5-22 What is the relationship between episodes of activity on the alluvial fans and eolian activity in the basin?
- 5-23 Can the intensity of occupation in the basin be correlated with episodes of eolian stability and instability?
- 5-24 What is the temporal sequence of eolian deposition on Otero Mesa?
- 5-25 What is the magnitude of the "floating" artifact phenomenon? Is spatial segregation in the frequency of occurrence apparent, or does it appear to occur in all eolian sands? Are artifacts truly "floating," or can other processes (e.g., gravity movement into blowouts, bioturbation) explain the observed phenomenon? If "floating" is confirmed, what processes appear to be responsible? Can the phenomenon be replicated experimentally?

Data needs: As many site-specific studies (see above) as possible are needed, with good coverage throughout the bolson and a high degree of temporal control. At least some prospection-level

investigations will also be required in nonsite contexts to assess areas where eolian sands may bury large groups of sites. Experimental, textural, and chemical analysis of associated sediments (at minimum) will be required to address the mechanics of artifact "floating" if such a phenomenon is supported.

These represent the really interesting questions associated with this environment on Fort Bliss. They are also not easy questions to answer, due to the sheer size of the post and the necessity to compile information from many different sites. However, they must be the focus of long-term research if the archeological record in the bolson and on Otero Mesa is ever to be understood within a regional landscape context.

5.2 ALLUVIAL FAN PROCESSES AND LANDFORMS

Alluvial fans represent deposits formed as streams undergo a reduction in gradient and a loss of confinement, such as typically occurs when a channel issues from a mountain front into an open valley. Typically, alluvial fans exhibit a wedge-shaped to semicircular plan morphology, a straight to gently concave-upward longitudinal (radial) profile, and a plano-convex transverse profile (Bull 1977; Nilsen 1985; Blair and McPherson 1994). Although alluvial fans occur in many different climatic settings, desert fans are among the most common and visible, and are clearly the most intensively studied type (Blair and McPherson 1994). This is particularly true in the basin and range province, where the characteristic steep ranges and alternating open graben valleys provide the perfect setting for their development.

The slope of alluvial fans varies from less than 1° to more than 25°, but most are inclined less than 10° (Bull 1977). Very steep, small fans are transitional between the typical fan and steep mass movement deposits termed talus cones, and are sometimes termed alluvial cones (Bull 1968). Where multiple fans emerge along a mountain front, they typically coalesce laterally, forming an alluvial *bajada*. Occasionally, broadly similar

features are formed along mountain fronts that do not exhibit the point-source character and radial symmetry of fans; these features are commonly termed alluvial slopes or alluvial aprons. Similar ramplike morphologies can also arise from eolian transport in the valley system, which can build large climbing dunes termed eolian sandsheet ramps at the valley margin (where they often overlie older fan systems) (Blair and McPherson 1994). Finally, pediments represent gently dipping erosional landforms in similar landscape contexts; while they are very different from fans and bajadas in terms of composition and genesis, they can appear very similar to thick alluvial bajadas in terms of their surface expression, particularly if mantled with a thin sheet of alluvium (Twidale 1981; Dohrenwend 1994). Collectively, these landforms make up the zone typically referred to as a mountain piedmont, which is transitional between highland and lowland areas.

Figure 25 presents a schematic view of an isolated alluvial fan system formed along a mountain front. All alluvial fan systems include two basic components: (1) a drainage basin, which consists of a coalescing dendritic drainage net and is the zone of net degradation (sediment loss), and (2) the fan itself, which consists of a constantly evolving, distributary drainage net and is a zone of net aggradation (sediment gain). Characteristic features of a fan system include the feeder channel, apex (or fan head), incised channel, intersection point, active depositional lobe, fossil (inactive) depositional lobes, and headward cutting gullies.

The feeder channel is the principal channel supplying sediment to the system. The point where the feeder channel emerges from the confining valley at the mountain front, initiating flow expansion and deposition, is termed the fan apex or fan head. In many cases, particularly on older, well-developed fans, an incised channel extends from the fan apex to a point farther downfan, or occasionally completely across the fan. Typically, the slope of this channel is less than the slope of the fan surface, so that the channel becomes progressively shallower with distance from the apex, finally merging with the

surrounding fan surface at a location termed the intersection point. Here, the flow expands laterally, forming a series of smaller, shifting distributary channels and dropping most of its sediment load. This results in the formation of a smaller, superimposed, fan-shaped area termed a fan lobe. The presence of an incised channel serves to shift deposition away from the mountain front, and facilitates basinward growth of the fan system.

With time, the active depositional lobe tends to shift laterally, or even be cut off completely, as the channel network evolves in response to complex interactions between morphology and sediment supply. Frequently, older lobes cut off from fresh sediment delivery by the fan-channel system may be dissected by headward-cutting gullies. If these gullies progress far enough up-fan, they can intersect and pirate the active channel system, causing the active lobe to be cut off. While the incised channel, fossil depositional lobes, and headward cutting gullies may be absent on many fans, the apex, intersection point, active depositional lobe, and some type of feeder channel is always present on active fans.

In terms of a short-term sediment budget, fan systems can be subdivided into three parts: (1) a zone of net degradation, which is situated in the drainage basin upstream from where the feeder channel enters the fan apex; (2) a zone of sediment bypassing, which is situated between the apex and the intersection point; and (3) a zone of net deposition, which is situated downfan from the intersection point. At a longer scale, all areas upstream from the apex are zones of erosion and all areas downfan are zones of deposition. Occasionally, an aggrading fan can build up to such an extent that the apex shifts upstream into the mountain front, decreasing the size of the drainage basin (Dohrenwend 1994).

5.2.1 Alluvial Fan Processes

Deposition on alluvial fans can occur by several basic processes: streamflow, debris/mud flow, and sheetwash. Streamflow processes involve

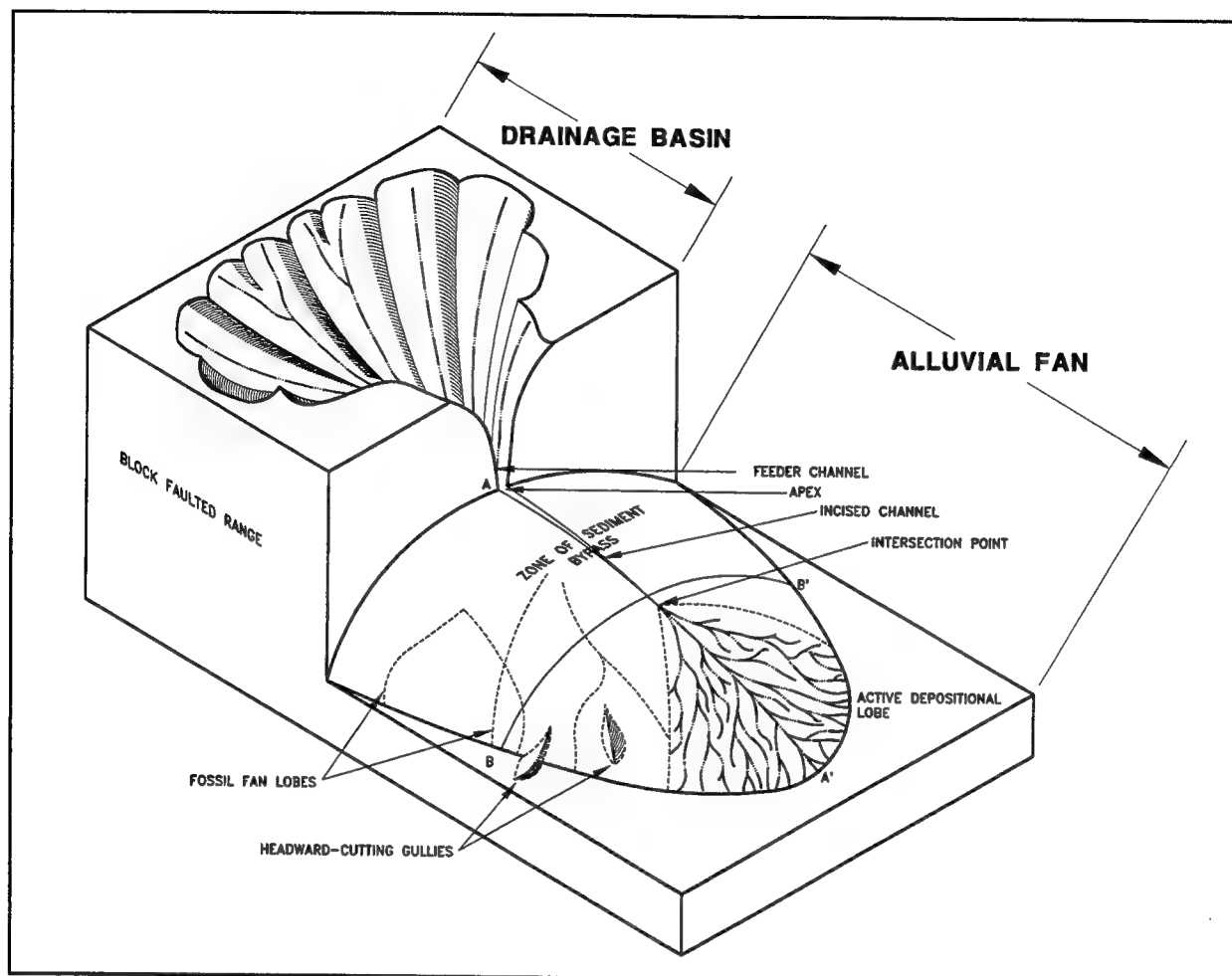


Figure 25 Illustration of an Idealized Alluvial Fan.

movement of sediment by water of appreciable depth, which generally occurs in a channelized situation (at a variety of scales, ranging from rills with depths of a centimeter or less to axial channels several meters deep). Like air, water is a Newtonian fluid, and transports sediment in traction, saltation, and suspension (see the discussion under Section 5.1.1). Unlike air, water can also transport sediments as solutes in the dissolved load. Other major differences between transport by water and transport by air include: (1) greater restrictions on the variability of flow direction in water transport, which is more strongly controlled by topography and essentially unidirectional (e.g., downslope); (2) increased competence due to the much greater density of water as a transport medium, resulting in the effective movement of much larger clasts; (3) less-

effective size sorting of particles due to increased fluid density; and (4) increased importance of traction and suspension transport, and corresponding decreased importance of saltation.

Debris flow and mudflow processes involve movement of sediment in a muddy slurry that is considerably denser than water and behaves very differently, creating distinctive deposits. Debris flows represent a transition between unconsolidated mass movements (landslides, mudslides) and true streamflow, and vary considerably in character depending on water content. Unlike flows in air and water, debris flows are moderately to highly viscous, and often exhibit many properties of plastic, non-Newtonian flow (Nilsen 1985). The character of flows varies considerably, however, and span the range from sediment-rich, plastic

flows to water-rich, quasi-Newtonian flow. Due to the high density of the fluid flow, cobbles and even large boulders can be carried in suspension, and settling is minimal within the fluid column, resulting in moderately poor size sorting to a total lack of size sorting in the deposits. Generally, relatively "wet" flows show some degree of internal sorting, normal or inverse grading, and uniform clast orientation, while more viscous flows tend to yield unsorted deposits with randomly oriented clasts. Frequently, debris flows begin as a sudden mass movement on a saturated, unconsolidated slope, shifting from an internally cohesive slip or slide to a viscous flow as speed increases. Debris-flow deposits are commonly associated with flash-flooding in the arid west of North America (Blissenbach 1954).

Sheetflow processes involve thin, aerially extensive sheets of water with little appreciable depth (on the order of a few millimeters or less) and tends to transport only very fine particles. Typically, sheetflow moving over the surface rapidly begins to organize itself into threads of weaving, channelized flow that diverge and converge in response to topographic irregularities and vegetation, such that distinguishing between true sheetflow (which is characterized by laminar flow, where the water molecules slide across each other in sheets, with no vertical mixing) and small-scale channelized flow (which is typically turbulent, and involves vertical and horizontal movement of individual molecules in the stream) is difficult. Thus, sheetflow often includes interspersed areas where laminar, turbulent, and transitional flow states exist. The term sheetwash is generally applied to the deposits of this suite of small-scale processes, regardless of the actual hydraulic behavior. Sheetflow is distinctly secondary to larger scale channelized flow and debris flow as an agent of fan deposition, and is probably most important as an agent of winnowing in alluvial fan deposits. With time, organization of the overland flow into streamlets can concentrate erosional energy, creating a network of small channels termed rills.

Deposition on alluvial fan surfaces is due to abrupt drops in flow competence resulting from changes in channel slope, channel confinement, and loss of water into the gravelly, permeable body of the fan. As the gradient decreases and flow expands, the depth of flow decreases, surface area increases, and velocity drops off. As a result, competence is reduced and deposition occurs. Blissenbach (1954) identifies three modes of deposition on arid alluvial fans: (1) flash-flood deposits, resulting from high-volume, sediment-laden flows of short duration; (2) stream deposits, which occur within and proximal to distributary channels; and (3) stream-flood deposits, which occur through flow expansion across the fan surface.

5.2.2 Alluvial Fan Deposits

Most researchers subdivide alluvial fan deposits into two types: (1) unsorted debris flow deposits; and (2) poorly to moderately sorted, water-laid deposits (Bull 1977; Reineck and Singh 1980). Debris flows are capable of transporting very large clasts for long distances over relatively gentle slopes. They generally result in the deposition of thin, broad sheets or lobes a few decimeters thick. Internally, these sediment bodies consist of unoriented, matrix-supported coarse clasts in a muddy matrix, and can exhibit a pseudovesicular structure due to the inclusion of trapped air (Reineck and Singh 1980). On the basis of replicative laboratory fans, Hooke (1967) suggests that most debris flow deposition occurs in the upper part of the fan, while water-laid deposits predominate downslope of the intersection point.

A variety of water-laid deposits occur within fans. Reineck and Singh (1980) identify three basic types of water-laid sediments: (1) stream channel deposits; (2) sheet flood deposits; and (3) sieve deposits. Stream-channel deposits and sheet-flood deposits are analogous to deposits formed by alluvial rivers, while sieve deposits are unique to the fan environment. Stream channel deposits result from confined flow within incised channels on the fan surface, and thus are typical of the higher portion of fans (i.e., above the intersection point). They are typically composed of coarse to

mixed load sediments, and may develop complex architectural relationships as a result of lateral shifts associated with aggradational and incisional episodes (Figure 26). Most channels are truncated, and consist of lenticular beds of poorly sorted gravels and sands, often exhibiting a gravelly lag at the base of individual scour fills. Cross-bedded sands may occur. The geometry of deposition varies considerably, but bars and multiple, ephemeral thalwegs are common within the boundary of the channel trench (Reineck and Singh 1980; Bull 1977).

Sheet-flood deposits result from flow expansion, typically downfan of the intersection point, where a network of bars and shallow distributary channels typically develops. They are typified by broad and thin sheetlike and broad lenticular deposits of moderately sorted to well-sorted sand and gravel. Cross bedding and parallel bedding are common, and gravels are typically well imbricated. Scour and fill structures do occur, but are much less common and more poorly developed than in the confined channels upfan (Reineck and Singh 1980; Bull 1977). Similar, thin deposits can occur away from the active depositional lobe due to poorly organized flow across the fan surface (Wells and Dohrenwend 1985).

Sieve deposits (also frequently termed sieve lobes due to their morphology) represent coarse deposits formed when water carrying primarily coarse clasts sinks abruptly into a porous substrate, causing the gravels to be deposited (Hooke 1967). Typically, sieve deposits are relatively well-sorted, poorly imbricated, and commonly occur immediately down-fan of the intersection point. Subsequent infiltration of fine-grained deposits (e.g., fine sands and silts) is common, resulting in a bimodal grain size distribution and a fabric of randomly oriented, clast-supported coarse gravels in a fine-grained matrix (Reineck and Singh 1980).

At a larger scale, alluvial fans typically exhibit a sequence of depositional facies that fine with depth, because as a fan grows, coarse material is shunted farther and farther into the basin (Rust 1979). The proximal part of semiarid and arid

fans is typically dominated by poorly sorted, matrix-supported, debris-flow conglomerates. Although debris flows may also occur, midfans are dominated by water-laid deposits, including normally and inverse graded clast-supported conglomerates and lenticular sand bodies. Distal fans are dominated by sandy to silty sheet flow deposits that exhibit parallel bedding and gently inclined planar crossbedding, and tend to grade subtly into basin facies. However, gravels may occur locally (Rust 1979; Reineck and Singh 1980).

The surface of alluvial fans in arid regions typically develops a characteristic surface armor of coarse clasts termed desert pavement. Typically, this gravelly surface is underlain by finer-grained sediments. For many years, this pavement was typically interpreted as an erosional lag of coarse clasts produced by eolian and/or sheetwash winnowing of gravelly sands and silts (e.g., Cooke and Warren 1973; Bates and Jackson 1984; Ritter 1986), although some authors (e.g., Mabbutt 1977; Dan et al. 1982) argued that they were the result of upward migration of coarse clasts due to shrink-swell processes. Because development by either of these processes implies that deposition on the surface has ceased, desert pavement surfaces are generally considered stable. However, recent work has cast doubt on these interpretations (McFadden et al. 1987; Dixon 1994). In fact, work by McFadden et al. (1987) documents at least one case where the pavement had to be formed by incremental additions of fine-grained material through eolian influx and in situ weathering, which served to raise detached surface clasts on a lava flow from the underlying bedrock. In other words, fine grained material infiltrates into the gravels on the surface, lifting them up until a lens of fine-grained allocthonous sediment lies between the intact basalt and the armor of basaltic surface clasts. This led McFadden et al. (1987) to conclude that "desert pavements are born and maintained at the surface," and propose a mechanism involving (1) colluvial movement of clasts into depressions filled with eolian sediment, and (2) detachment and uplifting of clasts from bedrock as salt-rich eolian fines accumulate in



Figure 26 Complex Fan-channel Deposits Exposed in an Arroyo on McGregor Range.

fractures, expand and contract with moisture variations, and force loose clasts upward. While it is debatable how widespread this phenomenon of aggradational pavements is (cf. Hooke 1990; Wells et al. 1990; Dixon 1994; Williams and Zimbleman 1994), it does indicate that the presence of a desert pavement surface does not necessarily imply that the surface is inactive.

A related question concerns the evolution of alluvial fan surfaces, which are typified by a channel and bar topography resulting from vectors of flow on the depositional lobe when active but tend to "flatten" into a relatively smooth surface with the development of a mature pavement surface (Hooke 1990). This process is related to weathering of the surface gravels, redistribution by colluvial movement, localized eolian deposition, and (disputably) creep processes. Whatever the process, this time-progressive decrease in microrelief can provide a valuable tool for determining the relative age of various portions of a fan (McFadden et al. 1989). Equally important,

it is possible that many of these processes of surface evolution can bury archeological materials, particularly those deposited in low spots on the irregular distributary surface, long after principal deposition of the surface has ceased.

5.2.3 Climatic Implications of Alluvial Fan Activity and Quiescence

Because they are typically the result of structural controls, alluvial fans may form under any climatic regime. However, studies of individual fans have demonstrated rough regional synchronicity in episodes of alluvial fan activity, which has led a number of investigators to identify changes in climate as the driving force behind alluvial fan activity in deserts (e.g., Gile et al. 1981; Wells et al. 1987; Bull 1979; 1991; Dorn 1994). Although the majority of authors cite climate change as the underlying mechanism stimulating fan activity, there is little agreement on the character of that change. Dorn (1994) identifies four climatic models of fan development: a transition-to-drier-

climate model, a paraglacial model, a humid aggradation model, and a periglacial model.

The transition-to-drier-climate model is probably the most commonly invoked (e.g., Gile et al. 1981; Mayer et al. 1984; Dorn 1988; Blair et al. 1990a; Monger 1993a). It assumes that a shift toward drier conditions results in a reduction in vegetation cover, which leads to increased sediment production as hillslopes become more vulnerable to erosion. Because vegetation response to climate change is not instantaneous, this implies that a lag period must exist between the onset of drier conditions and the geomorphic response. It also implies that the preceding, moist period was conducive to weathering and the maintenance of a mantle of weathered regolith on the slopes of the drainage basin. This model is generally espoused in the Fort Bliss region (Monger 1993a; Blair et al. 1990a; Gile et al. 1981).

In contrast, the humid-period-aggradation model argues that more effective moisture results in more efficient delivery of sediment, leading to the aggradation of fans during the wetter time periods (Lustig 1965; Barsch and Royse 1972; Mulhern 1982; Ponti 1985). Although not generally espoused in southern New Mexico, this relationship has equal theoretical viability and cannot be dismissed out of hand. In contrast, the paraglacial and periglacial models argue for the production of abundant sediment in the source basin by glacial processes and by cryoweathering processes, respectively. All extant paleoenvironmental data suggest that neither of these latter models is applicable to Fort Bliss, particularly during the culturally relevant timespan.

One additional model that Dorn (1994) does not address in any detail is the argument that episodes of alluvial fan activity can be stimulated by changes in the intensity or annual timing of precipitation, which does not necessarily require major shifts in vegetation density. Given that the climate of the Fort Bliss region appears to have been relatively arid throughout the Holocene, and thus should have supported discontinuous grasscover at best, it can be argued that variability

in sediment production could as easily be a function of the frequency of individual intense storms, which would control the rate of sediment delivery, rather than the density of erosion inhibiting vegetation.

In addition, there is another school of thought that holds that external stimuli are not necessarily required to initiate change in arid fluvial systems (e.g., Patton and Schumm 1975; 1981; Schumm 1977). This model argues that because sustained flow is not present, sediment is shunted through the system in short "hops," such that loci of erosion and deposition shift constantly under relatively uniform conditions. To cite one example, initiation of a headward-cutting gully on the surface of a fan will cause sediment to be deposited at its mouth, because flow will not be sufficiently sustained to flush the sediment out of the system. This process will result in a distributary lobe at the mouth of the gully that may aggrade sufficiently to bury the lower reaches. Thus, the gully may expand headward while at the same time burying itself with freshly exhumed sediment at its lower end, thus essentially migrating up the fan. Similarly, aggradation and downcutting may alternate systematically within the main incised channel of a fan, occasionally burying the channel completely and resulting in renewed distributary deposition on the upper fan surface. A related issue is the concept of complex response, which proposes that a single stimulus (such as a change in climate) can initiate a number of successive changes in geomorphic behavior as the system adjusts to reach equilibrium with the new conditions (Schumm 1973).

In sum, the linkage between climate change and geomorphic response of alluvial fan systems is complex, and it is unlikely that a satisfactory process-response model of fan systems that is simple and universally applicable will ever be formulated. Rather, the response of arid fans is complex and dependent on the magnitude, direction, and rapidity of climate change as well as the preexisting state of many system variables; the resulting stratigraphic sequence is the combined result of both extrinsic controls (including climate

change) and intrinsic processes. Thus, aggradation or erosion of fan channels may result from either shifts toward moister or drier conditions, changes in the intensity or timing of precipitation, or intrinsic systemic adjustments. Although the initiation of Organ fan deposition around 7 ka clearly seems to be related to a shift in aridity, the stratigraphic breaks between Organ I/Organ II (2.1 ka) and Organ II/Organ III (1.1 ka) are more tenuous, and should not be attributed *a priori* to increased aridity.

5.2.4 Geoarcheological Implications of the Alluvial Fan Environment

The alluvial fans of Fort Bliss are extensive and represent an important component of the overall landscape. Thus, archeological sites should be expected in the alluvial fan context, and extant surveys (e.g., Beckes et al. 1977; Skelton et al. 1981) reveal that archeological sites are indeed prevalent on the fans of Fort Bliss. Thus, interpretation of these sites requires an appreciation for the biases imposed by the geomorphic environment.

There are five geoarcheological implications of alluvial fan formation processes. First, because loci of deposition are localized on an alluvial fan and tend to shift with time, the stratigraphic sequence should be highly variable; stratigraphic correlation of time-equivalent deposits across the broader fan environment is complex and may not be possible using purely architectural relationships. Several alternate lines of evidence, including soil stratigraphic, archeological, and (less confidently) lithostratigraphic evidence, can be used to facilitate correlation, but chronometric data are an absolute necessity to establish a reliable sequence. It is important to realize that various archeological components of the same age may be simultaneously exposed at the surface and buried at a variety of depths on different parts of the same alluvial fan.

Second, the character of deposition in entrenched and unentrenched portions of the active portion of an alluvial fan are profoundly different, and have

varying potential to seal and preserve archeological materials. Deposits formed within the casement valley of an incised arroyo channel can represent considerable tractive force, and any archeological deposits contained therein can therefore represent highly reworked material. On the other hand, deposition here can also occur rapidly, and some components can be buried in near-pristine context. In contrast, archeological materials associated with distributary sheet flood deposits are less likely to be deeply buried, experience generally less-tractive force, and are thus less likely to be strongly reworked than material in the channels. However, they are still subject to considerable lateral disturbance during burial and are more subject to vertical disturbance by pedogenic processes, including bioturbation.

Third, even after the cessation of primary deposition on any given portion of an alluvial fan, secondary processes (including eolian, slopewash, colluvial, expansion-contraction, pedologic, and bioturbation processes) continue to modify the sediment. Low magnitude channelized flow associated with precipitation falling on the fan surface (as opposed to in the drainage catchment) can also result in reworking and burial of archeological components on "inactive" portions of the fan. Thus, it is possible that sites may be formed and subsequently buried on a relict lobe of a fan, particularly if they are situated within a topographic low. The presence of a surficial gravel lag, or desert pavement, does not preclude the possibility that archeological components may be buried at depth.

Fourth, the locus of water delivery on an alluvial fan shifts through time as the drainage net evolves, both laterally due to changes in distributary channels and axially as the intersection point shifts up- and down-fan in response to channel aggradation and incision. Thus, currently observable areas of water delivery on a given fan can be expected to be different than they were in the past. This is particularly important if one is looking for evidence of dryland agricultural fields designed to exploit infrequent summer runoff. Although the extent of prehistoric agriculture

practiced in the bolson is unclear, at least some agriculture was practiced during the Mesilla and (particularly) El Paso phases, and it is likely that intentional modifications of the landscape to provide for opportunistic irrigation of these fields were practiced. However, only a few water control structures have been identified in the region (Hubbard 1987; Leach et al. 1993), and such structures are conspicuously absent in the larger surveys (e.g., Skelton et al. 1981; Beckes et al. 1977). Better understanding of the areas experiencing active runoff during this time period could potentially allow more such structures, and possibly associated habitation sites, to be identified.

Last, if desert pavement on an alluvial fan surface has formed by sheetwash and/or eolian winnowing or by clast heave, then gravels should be present in the subsurface. If, instead, the pavement is formed by the "born at the surface" model of McFadden et al. (1987; Wells et al. 1995), then the sediment beneath the gravel armor should be exclusively eolian dust. In either case, the potential for buried archeological sites beneath the pavement is not high.

5.2.5 Alluvial Fans on Fort Bliss

Alluvial fans are a very important and extensive environment on Fort Bliss. The margins of the graben basin are marked by a series of large alluvial fans of different ages that have coalesced into bajadas that extend kilometers away from the mountain front. Monger (1993b) has correlated these fans with similar features identified in the desert project area (Gile et al. 1981). Another sequence of fans, largely unstudied, are preserved on Otero Mesa. It is unclear how these spatially discrete fans are related to the larger fans in the basin. The following discussion outlines the basic morphostratigraphic and soil stratigraphic framework of alluvial fans in the bolson.

Jornada I fans are the oldest, highest-elevation fans in the project area, and represent the oldest post-Camp Rice sediments in the study area. Typically, they dip fairly steeply into the basin, and are

exposed near the mountain front and buried basinward. Gile et al. (1981) date Jornada I fans in the desert project area to between 250 and 400 ka. Jornada I fans are characterized by stage IV carbonate morphology and, occasionally, strong argillic horizon development (although the solum of these old features is typically absent due to erosive truncation). In some cases, fine-grained facies exhibit stage III carbonate morphology. Monger (1993b) maps Jornada I fans around the margin of the Hueco, Jarilla, Franklin, and Organ mountains.

Jornada II fans are younger fans that are inset into Jornada I fans near the mountain front and tend to bury the more steeply dipping Jornada I fans basinward. Gile (1987b) estimates the age of Jornada II deposition as 150 to 25 ka. Diagnostic pedofeatures include intermediate carbonate development, ranging from stage III or incipient stage IV morphology in gravelly sediments and from strong stage II to stage III morphology in fine sediments, and a relatively strongly-rubified argillic horizon (when preserved, which is not common). Monger (1993b) maps Jornada II fans around the base of the Organ Mountains; they are absent on the Hueco and Jarilla fan-piedmonts.

Isaack's Ranch fans are in turn inset into the Jornada II. This surface dates to approximately 15 to 8 ka, and is mapped only around the Organ Mountains (Monger 1993b). It is characterized by stage II carbonate morphology in fines and in gravels, and a sparsely preserved, weak argillic horizon (Gile et al. 1981; Monger 1993a).

Organ Fans are the lowest alluvial surface preserved on Fort Bliss, and date to between 7000 and 100 BP (Gile et al. 1981). In medial fan reaches, the surface of the Organ unit often preserves the primary channel-and-bar topography that is largely eradicated on the older fans (although a secondary network of small channels can often be developed in a thin, surficial mantle of more recent sediments on these surfaces). Basinward, the organ alluvium becomes fine grained and grades almost imperceptibly into the basin floor; like the basin, the distal fan surfaces

are often mantled with recent dunes. Organ sediments are characterized by stage I carbonate morphology or a lack of pedogenic carbonate, very weakly argillic to cambic B horizons, and (occasionally) a faint reddish-brown color.

Arroyos are common on the fans, and typically expose complex stratigraphic sequences that suggest that the incised channels have experienced a complex history of aggradation, incision, lateral migration, and avulsion. Little is known about the relatively thick late Quaternary stratigraphic record preserved in the incised reaches of the fan channels, and what is known is based on research in the Desert project field area.

Similarly, limited investigations on the fan piedmonts commonly indicate multiple generations of thin, stacked deposits with variable amounts of truncation (e.g., see Monger 1993a, soil pedon descriptions). The older fan surfaces, in particular, frequently are capped by a veneer of sediment of considerably younger age, and it is not unusual to find areas where the fan surface was truncated to calcrete prior to deposition of a 1 to 2 m veneer of younger sediment (Abbott 1995; Monger 1993a). Thus, large-scale mapping of morphostratigraphic surfaces alone is insufficient to eliminate the possibility that buried archeological materials exist.

Desert-pavement surfaces in the region are typically relatively poorly developed in comparison to intensely studied pavements elsewhere (e.g., the Mojave Desert). Desert varnish is weakly developed, if at all. The packing of surface clasts is also typically relatively loose, with fine-grained sediment exposed in the interstices, which would render them vulnerable to attack by sheetwash. One common feature is apparent disturbance of the armored surface, indicated by irregular orientation of carbonate pendants on the clasts. These carbonate pendants are one of the first forms of pedogenic carbonate development in gravelly materials (Gile et al. 1966; Machette 1985), and appear to have developed in situ. However, the fact that up to 25% of the clasts frequently have pendants that are oriented up suggests that disturbance of the pavement is widespread.

Although the mechanism of this disturbance is unknown, it may be due to either reworking by sheetwash (which has strong implications for the potential for site burial) or livestock trampling (which does not), or both.

Another area of interest that remains relatively unexploited concerns the fans on Otero Mesa. These fans, too, exhibit surfaces and fills of various ages. At present, very little is known about these fans, and it is unclear how they correlate with the larger fans in the bolson.

5.2.6 Research Questions

The following research questions pertain to the alluvial fan environment. They are subdivided into site-specific questions, which should be addressed at each investigated site, and regional questions, which can only be addressed through the integration of a large number of site-specific studies.

5.2.6.1 Site-Specific Questions

- 5-26 What facies are represented at the site?
What facies contain cultural material?
- 5-27 What is the architecture of these facies?
- 5-28 Is the deposition characteristic of confined (fan channel) or unconfined (distributary lobe) flow? What can be said about local microtopography at the time of deposition?
- 5-29 What energy conditions are implied during deposition?
- 5-30 Is there evidence of erosive truncation?
- 5-31 Do the archeological remains appear to be the same age as the encasing sediment, or are they older?
- 5-32 What is the morphology of the present surface, and what are the implications of

this morphology for the local dynamism of the environment?

Data needs: Data needs include extensive (mechanical) exposures, aerial photo coverage, and chronometric data of alluvial fan depositional environments.

As in the eolian environment, interpretation of sites in the alluvial fan environment requires sufficient "windows" into the subsurface to define lateral variability in sedimentary units and soil development. High-quality aerial stereopair photographs can provide an invaluable tool for mapping the distribution of different depositional units and facies variation within units, particularly when coupled with ground-based stratigraphic, sedimentologic, and pedologic data. Once again, chronometric data is a virtual necessity to understanding the interrelationships between site components and the role of the site in the larger landscape context.

5.2.6.2 Regional Questions

5-33 How well do the data from individual sites support direct correlation with the Desert Project (Gile et al. 1981)? Are the two sequences really synchronous?

5-34 What is the sequence of Holocene aggradation and erosion represented in fan channels on Fort Bliss? To what extent are Holocene deposits preserved in these cut-and fill sequences? How does this sequence relate to the overall sequence of fan activity?

5-35 What is the variability in timing and magnitude of alluvial fan activity between the fans associated with the Organ Mountains, Jarilla Mountains, Sacramento Mountains, Franklin Mountains, Hueco Mountains, and the Otero Mesa scarp? In other words, do fans in various parts of Fort Bliss exhibit synchronous or asynchronous behavior?

5-36 Are there deposits of Late Pleistocene to Early Holocene age (e.g., Jornada II/Isaack's Ranch) associated with the fans on the eastern side of the bolson, where associated morphogenetic surfaces are not mapped?

5-37 Is there evidence for time-transgressive autocyclicity in the fan-channel temporal record, or do incision and aggradation appear to be synchronous along fan-channels and between fan systems?

5-38 What is the magnitude of deposition associated with distributary distribution at the mouths of incised fan channels? How thick and extensive are these deposits, and how rapidly do they appear to shift locations on the fan?

5-39 What is the magnitude and variability of deposition away from the active depositional lobe? Is eolian influx important in this environment? Do the pavement surfaces represent long-term stability, or could archeological materials be buried beneath them?

5-40 What is the relationship between El Paso and Mesilla phase sites and contemporary organization of drainage on the fans? Are these sites commonly situated near then-active distributary lobes? Is there any evidence of intentional modification of the fans to facilitate agriculture?

Data needs: A large number of well-dated sequences from individual sites are needed in a variety of alluvial fan contexts.

These questions can only be answered when a large database of information from individual sites in a variety of locations is compiled. They represent the second phase of investigation. While some questions could probably be answered relatively quickly with a limited number of individual studies (e.g., the questions about the

desert pavements), others will require a very large number of sites to address properly.

5.3 UPLAND AND SLOPE ENVIRONMENTS

The third major geomorphic environment on Fort Bliss consists of the slopes of the mountains surrounding the bolson. Here, broad erosional facets interdigitate with smaller, depositional areas. The slopes are also the location of rockshelters, which can provide highly detailed cultural and paleoenvironmental records.

5.3.1 Slope Processes

Geomorphic activity on the slopes is typically dominated by gravity-driven processes termed mass movements, with the activity of water playing a distinctly secondary role as an agent of transport. Mass movements can be divided into categories on the basis of several characteristics, including the type of material undergoing movement, the integrity of the moving mass, the speed of movement, the character of the shear zone, the dominant vector of movement (i.e., either vertical or horizontal), and the degree of moisture or lubrication involved (Chorley et al. 1984; Carson and Kirkby 1972; Selby 1982).

Materials involved in mass movement may be either rock, sediment, soil, or combinations of the above. Frequently, other materials (including vegetation, unfortunate people or animals, and, most relevant to this discussion, artifacts) are also incorporated into the moving mass and redeposited. One important factor that differentiates between various types of mass movement is the integrity of the moving mass. Consolidated mass movements consist of translation of intact or nearly intact blocks of rock or sediment, while unconsolidated mass movements do not maintain their internal integrity during movement. Frequently, a mass movement may start out consolidated (e.g., a rotational slump) and disintegrate into an unconsolidated movement (e.g., a flow) as the failure continues.

Speed is another important factor in differentiating between mass movements. Rapid mass movements occur in timeframes short enough to be perceptible to a casual observer, ranging from near-instantaneous (e.g., a rock falling off a cliff) to a span of a few days (e.g., a slow-moving mud flow). Incremental mass movements, in contrast, occur gradually over longer spans of time, ranging from weeks to tens or hundreds of years.

With the exception of creep processes, all mass movements require some type of shear zone, where the material undergoing movement detaches from the underlying substrate. This shear zone can be related to surface-weathering phenomena, inherent zones of weakness in the bedrock or sediment (e.g., bedding planes or joints), or simply loci of maximum stress within a relatively homogeneous body. In addition, they may be either planar or curved, and can occur as discrete shear planes or as broader zones of failure.

The direction of translational movement is another factor to consider. Some mass movements are nearly vertical, while others also involve considerable horizontal movement. Finally, the degree of moisture or lubrication involved in failure and movement is a major factor distinguishing various forms of mass movement. This lubrication is often provided by water, but can also be provided by ice or snow. Once a rapid mass movement is initiated, trapped air can also provide hydraulic support, and is an important factor in decreasing friction in large, catastrophic slides and flows, allowing them to sometimes travel great distances and "ride over" topographic irregularities in their path. Table 12 illustrates the major classes of mass movements that can occur in a warm desert environment like south-central New Mexico.

Mass movements occur when the shear stress imposed by gravity exceeds the shear strength of the material, which is a function of friction in unconsolidated material and mass strength in consolidated materials. Many factors can cause shear stress to exceed shear strength, either by increasing the former or reducing the latter.

Table 12 Classification of Mass Movements Typical of Warm Deserts.

| Primary Mechanism | | Type | Materials | Moisture Content | Rate of Movement | Description | Potential for Preservation of Archeological Context |
|-------------------------------|---------------------|-----------------------|-------------------------------------|--------------------------------|-------------------------|--|---|
| Lateral Movement Predominant | Creep | Rock Creep | plastic rocks (e.g., clays, shales) | low | very slow | slow plastic deformation of soft rock under gravity | n/a |
| | | Continuous Creep | soil/sediment | low | very slow | slow plastic deformation of sediment under gravity | high |
| | Flow | Dry Flow | sand or silt | very low (air lubrication) | very rapid | funnelled flow down steep slopes of noncohesive sediments | very low |
| | | Debris/Rock Avalanche | rock/ice | low (air lubrication) | very rapid | catastrophic, long-distance, low-friction movement of large volumes of rock and ice; can override significant topographic features | very low |
| | | Slow Earthflow | soil/sediment | low | slow | confined elongated flow | low |
| | | Mud Flow | soil/sediment | very high | slow | confined elongated flow | low |
| | | Rapid Earthflow | soil/sediment | very high | very rapid | rapid collapse and lateral spreading of soil/sediment | very low |
| | | Debris Flow | rock/soil/sediment | high/very high | very rapid | dense rapid flow usually confined in preexisting drainage routes | very low |
| | Translational Slide | Rock Slide | coherent rock mass | low (air lubrication) | very slow to very rapid | shallow slide along fracture plane | low/moderate |
| | | Block Slide | fractured rock mass | low (air lubrication) | moderate | shallow slide along fracture plane | low/moderate |
| | | Debris/Earth Slide | rock debris/soil/sediment | low/moderate (air lubrication) | very slow to rapid | shallow slide of deformed or undeformed soil/sediment masses along failure plane | low/moderate |
| | Rotational Slide | Slump | rock, rock debris, or soil | low to moderate | slow | rotational movement along concave-up failure plane | moderate |
| | Heave | Soil Creep | soil/sediment | low | very slow | widespread, noncoherent, incremental downslope movement of soil particles | moderate/high |
| | | Talus Creep | rock debris | low | very slow | widespread, noncoherent, incremental downslope movement of rock particles | moderate |
| Vertical Movement Predominant | Fall | Rock Fall/ Topple | coherent rock mass | low | very rapid | detachment and fall of blocks from vertical faces | low |
| | | Earth Fall/ Topple | coherent sediment mass | low | very rapid | toppling of cohesive masses from near-vertical faces of earth (e.g., stream cutbanks) | low |
| | Subsidence | Cavity Collapse | rock, soil, or sediment | low | very rapid | Collapse of rock or soil into underground cavities (e.g., dolines) | low |
| | | Settling | soil/sediment | low | slow | lowering of surface due to ground compaction, usually as a result of ground water withdrawal | high |

Modified from Summerfield 1991.

Factors that can increase shear stress include the removal of lateral support (e.g., by lateral erosion), removal of underlying support (e.g., by stream undercutting or another mass movement), slope loading (through the accumulated weight of infiltrating water, vegetation, and/or accumulated debris), lateral pressure (e.g., freeze-thaw, shrink-swell, pressure release), and transient stresses (e.g., earthquakes, wind blowing on trees). Factors that

can reduce shear strength include progressive weathering, structural changes or development, changes in pore water pressure, changes in interparticular cohesion due to wetting, or organic effects like animal burrowing or root decay (Summerfield 1991).

Other active processes on slopes can include slopewash, rill erosion, and rainsplash. Slopewash

can involve sheet flow and small-scale, poorly organized channelized flow, which can erode small channels termed rills that serve to increase organization in runoff patterns. Rainsplash refers to the detachment of particles by the energy of raindrop impacts; because sediment thrown downslope tends to travel farther than sediment thrown upslope, over the long term, this process tends to result in net downslope sediment movement. Finally, solution processes form an important part of slope development. Solution is responsible for the development of most caves and rockshelters, which form an aerially insignificant but culturally important part of the slope environment. Most surface water and ground water is actually a weak solution of carbonic acid, which forms through the reaction of water and carbon dioxide. Although the character of the reaction is complex, the net result is that this solution is able to attack and dissolve calcite, which is the primary constituent of limestone. Solution weathering occurs as water moving through cracks and fissures in bedrock dissolves the surrounding rock, eventually forming large voids (caves). Solution can be particularly efficient at seeps and springs where the groundwater emerges, which is the most common mechanism of rockshelter formation (although loss of support by solution of underlying strata can lead to collapse of shelter and cave walls and roofs, adding to the process). Solution can also attack surface rocks and sediments, carrying components of the slope away as water flows off the surface or through a sedimentary cover.

5.3.2 Slope Landforms

Slope morphology is typically described by subdividing a complex hillslope into segments (or facets) that have relatively simple geometric shapes (e.g., convex, straight, or concave) in each of two axes (e.g., parallel with and perpendicular to the slope); thus, nine basic slope facet forms can be identified (which can nonetheless vary considerably with inclination and degree of curvature) (Figure 27). Typically, slopes can be divided into a convex erosional upper slope, a straight middle slope, where transport is dominant, and a concave

depositional lower slope. However, the dimensions of these various segments can vary considerably, and geologic controls can cause the development of a complex sequence of segments to form. The depositional lower slope can also be absent if an efficient transport agent (e.g., a stream) is present to remove accumulating debris.

In humid environments, the rate of weathering typically outpaces the rate of denudation, and relatively smooth, sediment-mantled slopes are typical. Rocks in arid environments, in contrast, weather relatively slowly and typically yield irregular slope profiles with more distinct facets and slope breaks. One common attribute of arid zone slopes are relatively steeply inclined bare rock faces, termed free faces, where the rate of retreat is entirely a function of the ability of weathering to detach rock for transport. The following discussion, in general, is only applicable

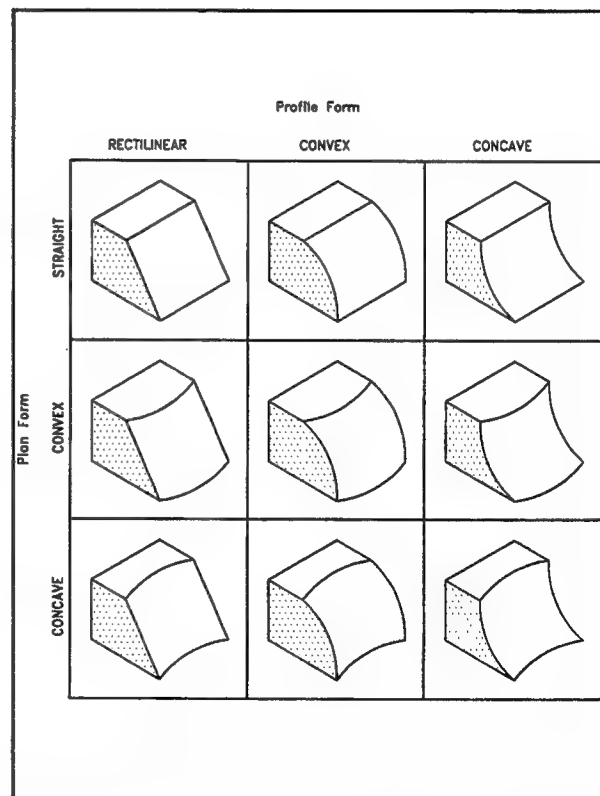


Figure 27 The Nine Possible Shapes of Three-dimensional Hillslope Facets. After Parsons 1988.

to arid environments where the rate of chemical weathering is relatively low.

Deposition on slopes creates sedimentary bodies that are collectively termed colluvium, although the term is sometimes restricted to masses of poorly sorted coarse- and fine-grained material. As rock detaches from a free face, it falls to the base of the slope, where it accumulates in the form of a coarse wedge of rock termed talus or scree. Talus slopes are typically steep because the rock accumulates until it rests at an angle of repose determined by the size, shape, and frictional properties of constituent clasts. Additional weathering can lead to further downslope movement and the formation of mixed coarse and fine material (colluvium) that typically lies at a gentler inclination than talus. If surface wash processes are sufficient to further transport the fine material, relatively thick wedges of dominantly, fine-grained sediment, termed slopewash, can accumulate.

The mode of slope evolution under arid conditions can be either downwearing or backwearing. If an agent of transport is available to remove the accumulating material at the base of the slope, then long-term, essentially parallel, retreat of the steep free-face can result in the development of a gently inclined bedrock surface termed a pediment. If, instead, the material at the foot of the slope is allowed to accumulate, the overall slope angle will decline through time as the steeper slopes are gradually replaced by gentler slopes and the height of the free face declines, resulting in a debris slope that tends to decrease in gradient through time (Figure 28).

The model presented above is overly simplistic, because the interactions between slope processes are more complex than indicated in this brief summary (cf. Abrahams et al. 1994; Carson and Kirkby 1972; Selby 1982; Parsons 1988 for in depth treatment). Rates and processes are governed by conditions that change through time as climate undergoes shifts; thus, efficiency of weathering and of transport will vary both spatially through time (Abrahams et al. 1994; Schmidt 1994). Moreover, differing thresholds may cause

various aspects of weathering and different transport agents to vary independently, so that both of the generalized models presented above may have acted on a given slope at various points in time. Vegetation can also play a role in the rate of weathering, the types of weathering products produced, and the speed of sediment removal from the system (Francis 1994). Finally, the character of slopes is also strongly conditioned by the characteristics of the bedrock. For example, a free face will typically only develop in relatively hard rock, while pediment-like forms may develop at least partially through downwasting and deep weathering (Moss 1977). Vertical changes in rock characteristics (e.g., due to stratified sedimentary rocks) can cause complex slope forms with many different segments to form, greatly complicating the many factors that must be understood.

5.3.3 Climatic Implications of Slope Activity

In general, because formation is dictated by the rate of weathering of rock underlying the slope, hillslopes are relatively resistant to climate change in comparison with other types of landforms. At the same time, this resistance implies that any climatically determined characteristics imposed on a hillslope system are more likely to be preserved through subsequent shifts in external conditions; thus, hillslopes are more likely to retain vestiges of attributes arising from long-past climatic conditions (Schmidt 1994).

Nevertheless, climatic influences are frequently apparent in slope morphology and slope sediment characteristics. In particular, when climatic changes influence rates of groundwater discharge at springs, activity levels on underlying slopes should vary with rates of discharge. Increased groundwater discharge not only increases the potential for slopewash erosion to occur, but can also stimulate mass movements by increasing the weight of sediments on the slope and decreasing interparticle friction.

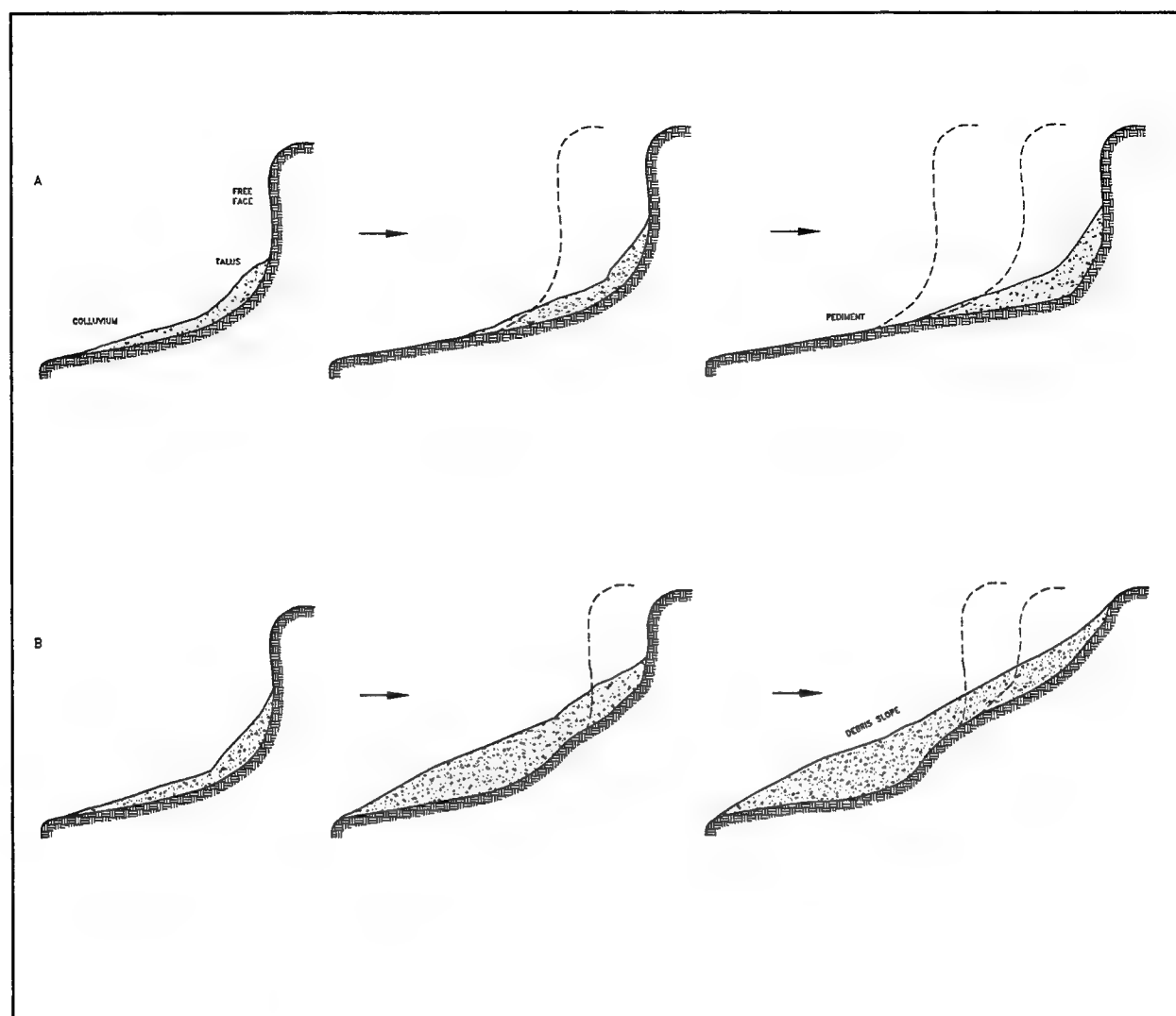


Figure 28 Two Generalized, Simplified Models of Arid Zone Slope Retreat. Parallel retreat and pediment formation resulting from efficient removal of colluvial sediments from base of slope (a) and slope replacement and debris slope formation resulting from inefficient removal of colluvium from base of slope (b).

Discharge may also stimulate groundwater sapping, as water emerging at an aquiclude (e.g., a contact between an overlying permeable sandstone and an underlying, impermeable mudstone) erodes the support of overlying beds, resulting in mass failure. Conversely, depending on the initial system state and the magnitude of the change in discharge, increased groundwater outflow can also lead to better development of anchoring vegetation, inhibiting slope activity.

Temperature changes also play a role. In particular, the frequency of freezing temperatures may strongly influence the rate of physical weathering of rock, and jointed rock in particular. Over the long-term, temperature and precipitation changes also dictate the rate of chemical weathering, in many cases profoundly influencing the stability of the slope.

Thus, the net effect of successive climatic perturbations can be a sequence of colluvial deposits that reflect former climates both in the rate of sedimentation represented and in the textural and chemical properties of the resulting sediment. Such sediments have been viewed as a proxy record of climate change (e.g., Devereaux 1982; Franschetti 1962). Nor are such controls limited to the slope system as a whole; similar trends in temperature and precipitation have been identified as important controls on the rate of rockshelter evolution (e.g., Laville 1976; Laville et al. 1980).

5.3.4 Geoarcheological Implications of Slope Environments

Because hillslope processes and process rates are so variable, archeological implications of geomorphic activity on hillslopes are particularly problematic to generalize. On the one hand, large, rapid mass movements can fundamentally alter the character of a hillslope in a matter of seconds, while on the other hand, many hillslopes evolve so slowly that they can be essentially viewed as constants within the relevant time range in North American archeology. Nevertheless, there are a number of broadly applicable geoarcheological implications of hillslopes and hillslope deposits.

First, archeological components developed on slope sediments that undergo rapid or slow progressive failure through mass movement and surface wash will be transported and redeposited along with those slope sediments; consequently, behaviorally significant spatial and stratigraphic context will generally be lost except in very broad terms.

Second, archeological components buried by rapid mass movements will also generally be disturbed to such an extent that spatial context is lost; however, stratigraphic context will typically be preserved.

Third, archeological components buried by incremental mass movements and slopewash will tend to operate as a slope sediment until buried; consequently, spatial context will typically once

again be lost, but in some cases may be preserved. Stratigraphic integrity in such a context should be moderate to high in most cases.

Fourth, the potential for preservation of spatial and stratigraphic context will decrease markedly with increasing slope angle.

Fifth, the potential for burial will be highest on concave slope segments. Thick accumulations of sediments should occur only at the base of the slope and at points where the colluvial material encounters a distinct reduction in slope, such as on bedrock-controlled benches.

Sixth, the sequence of colluvial sediments should reflect changes in sedimentation rates that mirror the degree of slope activity through time and may reflect climatic changes stimulating that activity. Shallow caves and rockshelters, too, should evince some cyclicity due to climatic changes. In particular, production of coarse debris should correlate with higher incidences of freezing temperatures, while production of finer materials should correlate with more pervasive chemical weathering.

Seventh and last, in some cases, incremental erosion of a stratified archeological hillslope deposit can lead to stratigraphic reversal, as increasingly old components are transported downslope and deposited on top of younger components.

5.3.5 Slope Environments on Fort Bliss

Very little attention has been focused on the slope environment on Fort Bliss. Most of the slopes are developed on stratified sedimentary rocks, and have therefore developed complex morphologies. Other slopes are developed on intrusive igneous rocks, particularly in the Organ and Jarilla mountains. Most slopes on the bolson margin are moderate to very steep; gentler inclines are typically underlain by alluvial fan deposits. The presence of ancient woodrat middens implies that, in general, the slopes are relatively stable; however, evidence of slide events is common,

implying that the slopes fail catastrophically on a localized basis. The character of the colluvial record, and the extent that this record may contain paleoenvironmental information, are at present unknown.

5.3.6 Research Questions

The following questions can be posed concerning the geoarcheological potential of sites on Fort Bliss that are situated on hillslopes. The first set of questions should be asked at each archeological site addressed in a slope context:

- 5-41 What is the character and thickness of sediments on the site? What processes were involved in deposition?
- 5-42 What age or ages are represented by the sediments? Do the archeological inclusions exhibit clear evidence for normal or reversed stratigraphy? Does the material appear to be in semiprimary or secondary context?
- 5-43 Are unconformities apparent in the colluvial sequence? What is the relationship between archeological inclusions in the sediment and those unconformities? Do the artifacts appear to have been transported and redeposited with the sediment, or simply buried by sediment derived from upslope?

Data needs: Extensive stratigraphic exposures, textural and chemical laboratory data to characterize site sediments and source sediments, and chronometric data are needed in colluvial depositional context.

Colluvial deposits are extremely difficult to deal with effectively because slope processes frequently do not result in deposits with clear architectural and stratigraphic relationships. Although soils can sometimes be used to help identify unconformities and estimate periods of stability and instability, the slow rate of soil formation characteristic of the region in general is exacerbated by rapid runoff

from the inclined surfaces. Nevertheless, most of the questions outlined above can usually be addressed to some extent, and in some cases detailed reconstructions of the sequence and timing of depositional events can be obtained.

The following questions are regional in scope, and can be addressed only after a number of site-specific studies have been conducted.

- 5-44 What is the character of the colluvial sequence preserved on Fort Bliss? Are thick colluvial deposits present, and if so, to what extent do they appear to be of culturally relevant age? What processes appear to have predominated?
- 5-45 How similar are colluvial deposits mantling the slopes of the various ranges flanking the basin? What does this similarity, or lack thereof, imply about the importance of regional controls in general, and climatic change in particular? What is implied about the variability of geomorphic processes involved in local slope evolution?
- 5-46 How does the colluvial sequence (if any is apparent) correlate with other evidence of climatic change? What types of changes appear to "turn on" and "turn off" colluvial activity? How sensitive to change does the slope system appear to be?

Data needs: A large number of well-dated sequences are needed from individual sites in a variety of colluvial contexts in each of the flanking ranges.

As in the eolian and alluvial fan environments, these questions can only be answered when a large database of information from individual sites in a variety of locations is compiled. Because only limited information will probably be obtainable from many sites, and because the focus of investigation is unlikely to be on the steep slopes (where military impact is generally not a problem),

it will probably take a number of years until answers can be formulated.

5.4 LACUSTRINE PROCESSES AND PLAYAS

Playas are ephemeral lake basins formed in arid areas with internal drainage (Reineck and Singh 1980), and are abundant in the Tularosa/Hueco Bolson (see Figure 3). They typically consist of level, smooth surfaces underlain by fine-grained sediment. Playa environments are an extremely important component of the overall Fort Bliss landscape from both geoarcheological and cultural perspectives. The principal significance of playas from an archeological perspective is that they form the only appreciable source of available surface water throughout the bolson, and thus would have been critical to extended occupation of the broad bolson floor. However, there is little likelihood that the playas held water for more than a few weeks at a time through the year, and utilization of the bolson would probably have required either careful scheduling or carried water.

From a paleoenvironmental perspective, playas are significant in that they can contain fine-grained, laminated sediments capable of preserving a variety of types of climatic and biotic data. Another significance of these sediments is that they represent some of the few exposed sediments occurring in the bolson with sufficient clay content to permit cohesion for puddled adobe. Coupled with the fact that they are also the only real source of the water needed for adobe manufacture, it follows that playas would have been important resources for construction material during the latter prehistoric period.

5.4.1 Mechanisms of Playa Formation

Several models of playa formation have been advanced in the geomorphic literature. In the eolian model, which is probably the most widely accepted, seasonal drying of the poorly vegetated, fine-grained playa surface results in desiccation, cracking, and subsequent deflation of the playa sediments, deepening the playa. This mechanism

certainly occurs, as evidenced by the frequent presence of lunette dunes downwind. However, other mechanisms cited as contributors to the formation of playas include (1) loss of volume in the sediments beneath the playa through solution of carbonates and other soluble salts in the near subsurface; (2) gain in volume (and accompanying elevation of the surface) of sediments outside the playa through the displacive growth of carbonate horizons that are inhibited in the playa by increased soil moisture; (3) faulting of basin-floor sediments due to regional tectonic processes; and (4) faulting due to solution collapse of evaporite beds at depth in the subsurface (Woodruff et al. 1979; Gustavson 1986). Most of the playas on Fort Bliss appear to be related to faulting in the basin (Monger 1993b), although other mechanisms may have played a role in their subsequent growth. Notably, the eolian model and the first two alternate models presented above cannot account for the initial formation of a playa, only for its growth after establishment, and none of the models are necessarily mutually exclusive.

No matter what their formative mechanisms, playas represent areas where precipitation and/or runoff collects and evaporates. Infiltration also occurs, but is typically inhibited by the fine-grained, low-porosity character of deposits in the playa. Deposits in the playas consist of both clastic sediments (typically silts and clays) contained in the water, and evaporitic minerals (e.g., gypsum, halite), formed as mineral-rich water evaporates. The size of playas is a direct function of the amount of precipitation and the rapidity of evaporation. One of the most common attributes of playa surfaces is the formation of polygonal dessication cracks, which can range up to 300 m across and 5 m deep (Chorley et al. 1994), but are typically much smaller. Motts (1970) distinguishes between fine-grained playas, which are typified by relatively smooth surfaces, and coarse-grained playas, which are characterized by "puffy" surfaces formed through capillary rise of water as evaporation progresses. One of the mechanisms that appears to smooth the surfaces of playas is wind action on shallow, broad sheets of standing water in the playas (Motts 1970).

Sedimentological studies suggest that most playas consist of irregularly bedded laminae of silt, clay, and evaporites (primarily gypsum) cut with dessication cracks. Glennie (1970) attributes the irregular bedding to the aggradation of adhesion ripples (a distinctive type of upwind-expanding, asymmetric ripple formed as blowing sand is trapped on a moist surface), but at least some of the irregularity in playa stratigraphy is clearly due to displacive growth of evaporite lenses. The relative amount of clastic and evaporitic material in a playa pan is largely a function of the mechanisms of water supply; those playas situated on the margin of a flat that are fed by runoff from adjacent fan systems will be relatively clastic-rich, while basin-central playas that are fed primarily by laterally-moving soil water tend to be evaporite rich, and can develop into salt pans consisting of a continuous crust of gypsum and evaporitic minerals. One such salt pan, formed by the contraction of pluvial Lake Otero, is the source of gypsum comprising the dunes at White Sands National Monument.

Sedimentologic studies are divided on whether playas are aggrading or degrading features (e.g., Blackwelder 1931; Stone 1956; Woodruff et al. 1979; Gustavson 1986), and there are indications that different processes may be occurring in different situations. For example, Motts (1965) suggests that Mojave Desert playas are generally degradational features, while playas in southern New Mexico and western Texas are slowly aggrading.

5.4.2 Climatic Implications of Playas

Because playas ultimately represent the interplay between precipitation and evaporation, it follows that variations in playa size should be largely a function of climate change. The rate of sedimentation in playas should also reflect precipitation, increasing proportionately to the volume of sediment-laden water delivered. In fact, playa dynamics should reflect a balance between sediment influx (either by alluvial processes or by trapping of eolian sediments by a moist surface) and sediment erosion (due to eolian activity), both

of which are directly related to climate. If the rate of influx exceeds the rate of erosion on an annual basis, then the playa should aggrade, while degradation would be promoted by more efficient wind erosion. Given that both of these factors are related to climate and may have varied in relative importance through time, examination and dating of erosional unconformities in a section through a playa pan fill could conceivably provide a proxy record of climatic conditions. However, localized effects (e.g., variations in sediment delivery due to shifts in the fan system feeding the playa and temporary eolian obstruction of the feeder system or burial of the playa) would have to be understood before such a record could be extracted. One of the most important variables in understanding the behavior of fan-marginal playas is the behavior of the drainage net on the distal fan, which can be expected to shift both in response to climate change and in an autocyclic manner. This factor alone could be responsible for the growth and abandonment of many playas.

The ultimate impact of minor shifts in precipitation intensity and timing on activity in a playa system are difficult to predict, and probably differ between individual playas, even in relatively localized areas. If the balance between aggradation and deflation is strongly tipped in one direction or the other, then alternation between intermediate-term aggradation and degradation should not occur as a result of these minor shifts; the net effect would be either changes in the rate of sedimentation or in the rate of deflation, and the types of climatically driven sequences in playa sediments proposed above would not occur. However, if the two processes are in rough equilibrium, such that minor changes could tip the balance back and forth across a threshold, a sequence of deposits containing significant unconformities could be expected. However, the process-response relationships associated with such changes are still unclear. For example, does relatively sustained flow resulting from longer-lasting, less-intense storms introduce more sediment into the playa because the overall volume of flow is increased, or do shorter, more intense storms result in more highly sediment-charged water that counteracts this tendency?

Does more frequent, low-intensity wetting of the playa surface promote eolian erosion by generating more surface cracking, or is more thorough, widely timed wetting more effective in freeing sediment for entrainment? Although no answers to these questions currently exist, and indeed may not be possible except on a case-by-case basis that allows for consideration of other important variables (e.g., texture and mineralogy of delivered sediments, size and character of sediment supply routes), it can be argued that playa behavior is controlled by climate, and thus there is potential for greater understanding of paleoclimatic conditions and climatic change through examination of the sedimentological record preserved in playas. Moreover, there is also strong potential for paleoenvironmental information through the examination of inclusions (e.g., pollen, diatoms, ostracodes) in the fill (see Chapter 6.0).

5.4.3 Geoarcheological Implications of Playas

There are four geoarcheological implications relevant to the playa environment. First, playas formed by faulting of basin floor sediments should exhibit elongate shapes and roughly linear spatial relationships that reflect this origin, while purely deflational playas should be more randomly shaped and oriented. Monger (1993b) notes that both deflational and tectonic playas exist on Fort Bliss. Fault-basin playas should also be asymmetric in cross-section, with the thickest sediments on the downthrown side of the fault, while purely deflational playas should be much more regular in cross-section, with the thickest sediments situated near the middle of the playa. Although both types could potentially exhibit groundwater/soil water discharge, stratigraphic offsetting of strata or soil horizons behaving as aquicludes would be more likely to result in such discharge in tectonic playa basins, suggesting that they may have been slightly more reliable water sources in the prehistoric past.

Second, appreciable sedimentation in playas should only occur if the rate of sediment influx outpaces the rate of deflation over the long term. If a playa develops only through eolian deflation, thick sediments should not develop, and the playa should be floored with the sediments filling the broader

basin. However, if the playa develops through tectonic processes, carbonate solution, or carbonate inhibition, thick playa sedimentation could still occur. Thus, useful paleoclimatic records are more likely to be associated with playas formed by processes other than simple eolian deflation.

Third, playa size should be a function of (a) effective precipitation; (b) effective evaporation; and (c) efficiency of the water/sediment delivery system. Thus, fan-margin playas, which are subject to the vagaries of flow on the distal fans, should exhibit relatively complex, asynchronous histories, while basin-central playas should exhibit more comparable histories. There should also be a tendency for fan margin playas to be better sources of water because of larger source areas.

Fourth, archeological sites should be rare in active playas but common on the playa periphery. Thus, archeological sites situated to exploit playa environments should reflect temporal periods when the particular playa was active, and ephemeral sites should coincide with annual peaks in precipitation (in this case, summer occupation). In most cases, extensive archeological sites should not be expected to be interstratified in playa sediments, although the remains of ephemeral sites may be common. However, the integrity of any such assemblage should be high unless strongly affected by pedogenesis or salt-crystal growth.

5.4.4 Playas on Fort Bliss

Playas on Fort Bliss are generally restricted to the Tularosa/Hueco Bolson. Many of these playas are apparently tectonically related, but dispersed deflational playas also occur (Monger 1993b). In general, the size of playas in the bolson has been diminishing since the Pleistocene, when many were fairly large due to the greater moisture influx and less effective evaporation.

Pleistocene age playas are associated with the Petts tank geomorphic surface, while Holocene-age playas are associated with the Lake Tank surface (Monger 1993b; Gile et al. 1981). The relatively few soil trenches excavated into playa deposits on

Fort Bliss (e.g., pedons 90-4, 90-5, 91-4, 91-5, 91-6 in Monger 1993a) suggest that soil development is typically fairly strongly developed, complex (e.g., A-Btk-Bk, A-Ak-Btk-Cgk-Bgk, and A-Btk-K-Bk-2Btk profiles), and relatively old, although recent surficial sediments were noted in pedon 90-5. Although primary depositional laminations were not noted in any of the profile descriptions, the soil data suggests that most of the trenches were excavated into older playa sediments (e.g., Petts Tank) where extended soil development may have masked primary structures. In short, inadequate investigations have been conducted to characterize the playa environment on Fort Bliss.

5.4.5 Research Questions

The following questions represent some of the most interesting questions relating to the playas on Fort Bliss. The first question is fundamental in that it dictates the scope of questions that can be addressed:

- 5-47 Do the playas contain appreciable late Pleistocene/Holocene sedimentary records, or are they largely erosional features?

If sedimentary records are preserved, the following questions are relevant lines of inquiry:

- 5-48 Are depositional units and erosional unconformities apparent in the playa sequences? If so, how do they compare between playas? Is there a difference between fan-marginal and central-basin playas? Between tectonic and nontectonic playas? What are the paleoclimatic implications?
- 5-49 Are datable organic materials preserved in the sequences? If not, how applicable are other forms of dating (e.g., OSL on sediments, radiocarbon ages on pedogenic carbonate)?
- 5-50 Are other forms of paleoenvironmental data (e.g., pollen, diatoms, ostracodes,

stable isotopes on soil carbonate) obtainable from the stratigraphic sequences (see Chapter 7.0)?

- 5-51 Can episodes of activity and inactivity be documented in fan-marginal playas? If so, how do they appear to relate to activity on the adjacent fan?
- 5-52 What is the relationship between the playas and eolian activity on the basin floor? Are there playas now buried by eolian sand?
- 5-53 What is the character of the record preserved in playa-margin lunette dunes? Can they be used to document episodes of activity and inactivity in the playa?

Data requirements: Extensive mechanical excavations are needed from playa sediments. Data from adjacent alluvial fan and eolian environments are also required to address the last three questions.

These are the basic questions that provide context for interpretation of associated sites and broader questions of geomorphology and paleoenvironments in the Tularosa/Hueco Bolson. They can then be used with additional data to ask more specific, cultural questions:

- 5-54 What is the character and age profile of nonarchitectural sites in the fan-marginal environment? Are there any indications of occupation seasonality? Are the sites ephemeral, or do they imply long-term residence? Were different types of playas used in the same manner, or were some types used more intensively? Do the ages of these sites agree with documented ages of playa activity?
- 5-55 Are architectural sites situated in a manner conducive to exploitation of playa sediments and water for pueblo construction? Is there any evidence of mining playa deposits for building

material? If not, what was the source of building material?

5-56 Are playa size and playa-margin site density related? In other words, were large playas utilized more intensively?

5-57 Is there any evidence that playas were used for agriculture? Is this even feasible, or do soluble salts occur in too great a concentration?

Data requirements: As above, combined with archeological data from surrounding sites.

The preceding questions address cultural interaction with the playa environment. They require considerable subsistence, location, and technological information that can only be obtained through detailed archeological investigation. The range of data required to address these issues cannot be adequately outlined here; the reader is referred to Chapters 7.0 through 12.0 for complete treatments. However, it is interesting to note that many Formative sites, and El Paso phase sites in particular, do seem to be situated in proximity to playas (Carmichael 1985b).

5.5 SOIL PROCESSES, SOIL MORPHOLOGY, AND SOIL GEOMORPHOLOGY

Soil formation, or pedogenesis, consists of a suite of physical, chemical, and biological processes that act upon and transform rocks and sediments at the earth's surface. The morphology of a given soil represents the interaction of five basic soil forming factors, first identified by Jenny (1941): climate, organisms, relief, parent material, and the duration of subaerial weathering (time). Soils have tremendous utility to questions of Quaternary landscape development and, by extension, to archeology. The principal benefit to archeological studies is essentially two-fold. First, soil geomorphology and soil stratigraphy can provide a mechanism for estimating the age of landforms and sediments, and thus provide constraints on the age of associated sites (Morrison 1967; Birkeland

1984; 1990). Second, understanding of the character of pedogenic transformations of the sediment matrix provides a means to address postdepositional disturbance of archeological strata (Butzer 1982; Schiffer 1987).

Climate is one of the most important soil-forming factors, in that it governs the types and rates of almost every pedogenic process. Variations in precipitation and temperature affect the rate of chemical and physical weathering, the types and abundance of vegetation and soil organisms, and the rate and character of soil-constituent translocation within the soil. Although there is a spatial component to the variability of climatic parameters (e.g., the mountainous areas on Fort Bliss receive more moisture and generally experience slightly lower temperatures than the bolson floor), for all intensive purposes, climate can be treated as a constant in consideration of the contemporary soil landscape. It does play a role, however, in the types of properties that develop in soils of different ages under varying climatic regimes, as relatively minor changes in annual precipitation can have significant influence on rates of pedogenesis.

Organisms in the vicinity of Fort Bliss are conditioned by climate. In addition to contributing organic material to the soil, both plants and animals are significant factors in the turbation of soil profiles. Thus, from an archeological perspective, the influence of soil organisms is of considerable interest in the preservation of archeological sites. Plant cover is also an important control on the rate of surface erosion, which can frequently outpace pedogenesis if the sediment is not anchored by vegetation. Thus, soil thickness and horizon development are frequently governed by vegetation characteristics.

Relief primarily refers to the slope of a locality and its surroundings, but also includes slope-aspect and surface smoothness (microrelief). Collectively, these characteristics, coupled with soil texture and vegetation cover, control the potential for moisture to infiltrate or run off. Infiltration provides the moisture that supports (or limits) the biotic

assemblage, allows chemical weathering to occur, and translocates soil constituents. Thus, when other factors are held constant, increasing relief results in successively thinner and less-developed soil profiles.

Parent material is the matrix that soil develops in, and can consist of either bedrock or sediment. Parent material exercises considerable control on soil development because it governs mineral content, weatherability, textural characteristics, and soil chemistry, and affects the depth and speed of infiltration, the character of relief development, and the nature of the biotic assemblage.

Finally, time exerts considerable control on soil morphology because almost all pedogenic processes are time-dependent and show increasing alteration of the parent material and spatial rearrangement of constituents with longer duration of subaerial weathering. This characteristic allows for the construction of soil chronosequences that can be used to obtain rough estimates of the length of exposure for both extant and buried surfaces. Although the rates of development of different properties can vary by several orders of magnitude, and eventually tend to reach equilibrium (Figure 29), variation in the expression of different soil properties (e.g., organic matter, extractable iron, manganese, clay, and carbonate content and morphology; soluble salt, phosphate, nitrate, and potassium content; mottling; rubification; pH; soil structure; soil consistence; horizon differentiation) can provide excellent criteria to correlate geomorphic surfaces and obtain relative ages of landforms and sediments.

5.5.1 Soil-Forming Processes

Although there are many processes involved in pedogenesis, this discussion will be limited to the most important processes operating in the general vicinity of Fort Bliss: organic matter accumulation, weathering, carbonate translocation and accumulation, clay translocation and accumulation, salt accumulation, and processes of turbation.

5.5.1.1 Organic Matter

Organic matter accumulation is typically the first detectable component of pedogenesis. However, biomass in the Fort Bliss region is low, and the rate of organic matter destruction by oxidation is high. Consequently, the accumulation of organic matter is a slow process and tends to reach rough equilibrium at relatively low concentrations (approximately 1% to 3% organic carbon). Thick, dark A horizons typical of more humid areas do not develop; rather, well-developed soils exhibit pale-colored surface horizons termed ochric epipedons (Soil Survey Staff 1990). However, older soils can contain considerably more organic carbon than younger soils due to the bonding of organics by clays in argillic horizons.

5.5.1.2 Weathering

Weathering is typically subdivided into two suites of processes termed physical weathering and chemical weathering. Physical weathering subsumes processes that break rock apart, producing smaller and smaller particles composed of the same constituent minerals. Processes involved in physical weathering include freeze thaw, salt-crystal growth, unloading, mechanical abrasion (e.g., sandblasting), and (arguably) diurnal expansion and contraction (Birkeland 1984; Chorley et al. 1984).

Chemical weathering subsumes a suite of reactions, including solution, hydration, hydrolysis, oxidation, reduction, and chelation, that attack and alter constituent minerals. The products of these reactions are frequently intermediate minerals that are themselves subject to continued weathering. The ultimate products of weathering, including various base-poor clay minerals and aluminum and iron oxides, are relatively stable under surface conditions (Birkeland 1984). They rarely develop in arid environments because insufficient moisture exists to flush soluble bases out of the system; thus, most clay minerals are expandable, base-rich varieties (e.g., montmorillonite), although more stable varieties (e.g., kaolinite) also occur. Chemical weathering liberates soil constituents,

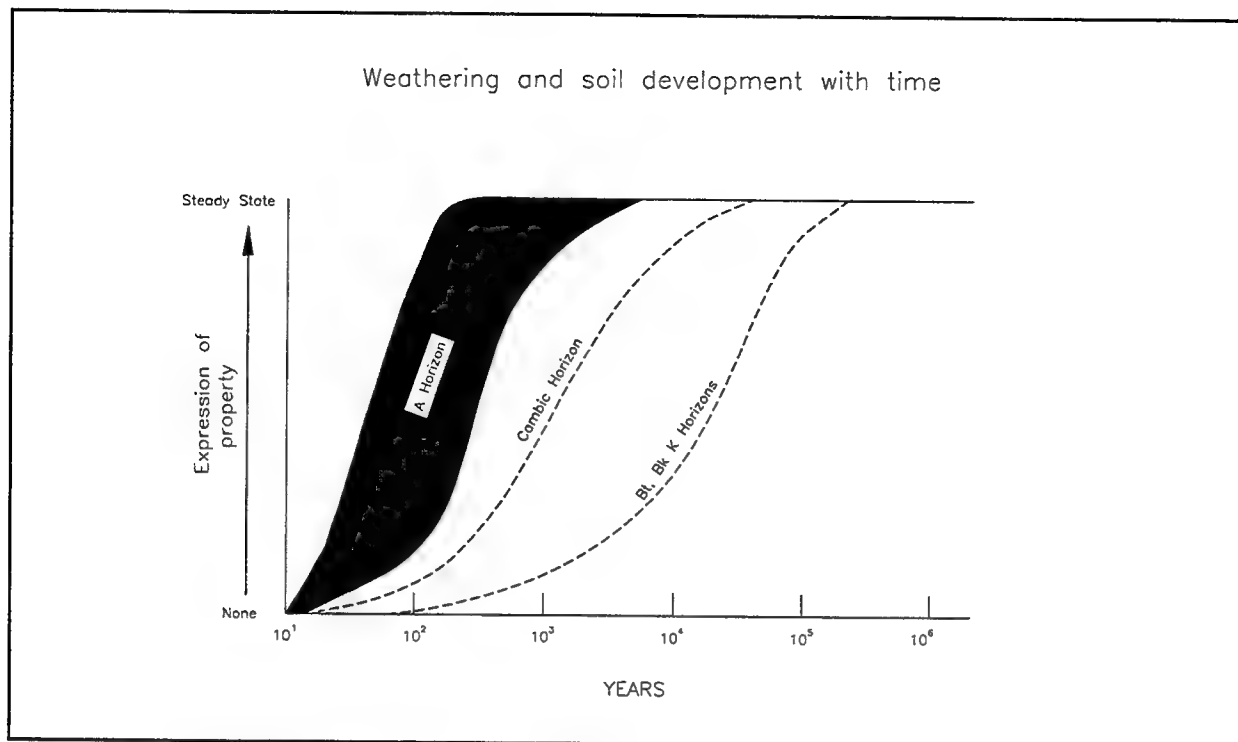


Figure 29 Illustration of the Time Necessary to Reach Steady-state for Various Soil Properties. After Birkeland 1984.

allowing them to be translocated in the profile. Typically, constituents are removed from the upper solum in a process termed eluviation, translocated down through the profile, and deposited or precipitated deeper in the soil in a process termed illuviation. However, in some cases, constituents (particularly soluble salts) can be brought up through the profile by capillary rise, often forming a crust at the surface as the water evaporates.

5.5.1.3 Carbonate Translocation and Accumulation

Carbonate accumulation in the subsoil is probably the best single time-diagnostic feature of soil profiles in semiarid and arid climates. Zones of carbonate accumulation are termed Bk horizons when authigenic carbonate is dispersed through the matrix and K horizons when authigenic carbonate engulfs more than 90% primary fabric grains (Birkeland 1984; Gile et al. 1981). A commonly used alternative classification, still favored by the Soil Conservation Service (Soil Survey Staff 1990), does not include the K horizon definition.

Rather, all zones of carbonate accumulation are termed Bk horizons, with the term Bkm used for indurated horizons (also termed calcretes). Carbonate accumulations in general, and calcretes in particular, are commonly referred to by the term *caliche*.

Gile et al. (1966) presented models of pedogenic carbonate accumulation in fine-grained and coarse-grained parent materials. Four stages of carbonate accumulation were recognized. This initial classification has been modified several times (e.g., Gile 1975c; Bachman and Machette 1977; Machette 1985; Birkeland 1984), and six stages are now recognized (Stages V and VI represent subdivisions of the original Stage IV morphology; Stages I-III are essentially unchanged). The following summary description of diagnostic carbonate stages follows these modifications to the original system of Gile et al. (1966), even though the original classification was used in the desert project in the Las Cruces area (Gile and Grossman 1979; Gile et al. 1981).

Stage I accumulations consist of thin, partial, or complete coatings in gravelly parent material and filaments and/or grain coatings in fine material. Due to the mechanics of water movement down through the profile, carbonate coatings in gravelly parent material typically develop on the bottom of clasts first (so-called meniscus carbonates, pendant carbonates, or gravity rinds), growing gradually upward around the clasts with time until the entire surface is covered with a fine carbonate coat that is thickest on the bottom of the clast. Similar grain-coats may occur in fine-grained material, but more common are carbonate films (diffuse coats on ped faces), filaments (very fine, linear accumulations commonly associated with fine plant roots or fungal mycelia), and threads (similar to filaments, but thicker). Phreatic zone (groundwater) carbonates are usually distinguishable because the meniscus thickening on the underside of clasts does not occur; such coats are said to be isopachous.

Stage II accumulations consist of thicker, more continuous clast coats with at least some interclast bridges or fillings in the interstices in coarse materials and the formation of carbonate nodules in fine material. In many cases, the nodules may be surrounded by low carbonate matrix, but clouds of soft matrix carbonate, overall matrix whitening, and thicker filamental carbonates may also be present. With increasing development, the size of nodules and the amount of internodular matrix carbonate increases. Occasionally, nodules may not develop; rather filaments increase to the point that overall volume of carbonate is similar to nodular horizons, and the designator II_f is used (Birkeland 1984).

Stage III accumulations in both gravels and fines are represented by abundant carbonate throughout the horizon that may be soft and chalky, but frequently becomes indurated and very hard. In latter Stage III accumulations, the horizon becomes plugged with carbonate, drastically decreasing permeability. Typically, Stage III carbonate accumulation occurs much more rapidly in gravels because so much of the matrix is occupied by rock. In both cases, carbonate matrix growth may

begin to force primary fabric grains apart. Another common feature of Stage III morphology (and higher) are rhizoliths, which consist of thin to relatively thick, tubular nodules accreted around plant roots. They frequently occur below the plugging horizon where the root allows deeper water penetration, and eventually seal off and kill the root.

Stage IV accumulations in both coarse and fine sediments consist of a thin, weakly expressed laminar layer composed of almost pure cemented carbonate (>75%) overlying a plugged horizon. Lamination develops as infiltrating water is stopped at plugged horizon and begins to flow laterally, dissolving and reprecipitating carbonate as it goes. Carbonate growth in the plugged horizon is usually sufficient to result in noticeable separation of framework clasts.

Stage V accumulations are characterized by thick laminar crusts, incipient brecciation (where the calcrete fractures and is recemented), and the initial development of pisoliths (irregular, concentric laminae of carbonate around a nucleus, which is typically a framework clast or a brecciated calcrete fragment). Deep cracks through the indurated horizon may develop, and the sides of these cracks often develop laminae of their own. As the laminated coating in these cracks grow, they can exert lateral pressure, causing the calcrete hardpan to fracture further.

Stage VI accumulations are characterized by thick laminar crusts, strongly or repeatedly brecciated and recemented K horizons, and strongly developed pisoliths. They usually indicate considerable antiquity.

The six stages of carbonate accumulation are illustrated in Figure 30. In general, Late Holocene deposits in arid climates exhibit Stage I morphology, while early Holocene and Late Pleistocene deposits exhibit advanced Stage I or early Stage II morphology. However, capillary groundwater rise can result in rapid precipitation of phreatic carbonate that can appear similar to Stage III pedogenic carbonates at a macro scale, although

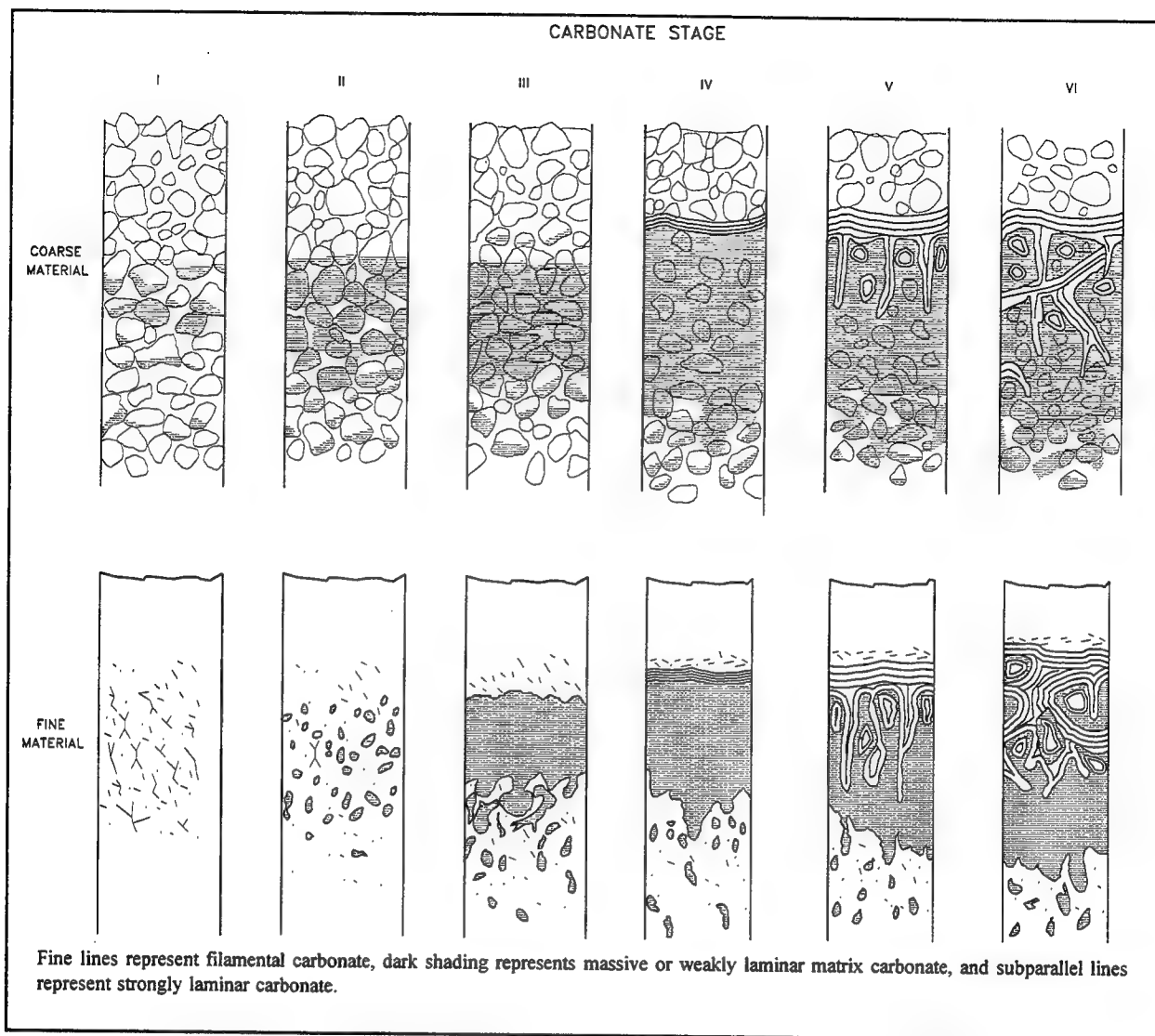


Figure 30 Illustration of Carbonate Stage Morphology Sequence. Based on figures in Gile et al. 1966 and description in Birkeland 1984.

they can be clearly differentiated microscopically (Goudie 1983).

Development of poststage III morphology is also time-dependent; however, radiocarbon ages on strongly developed calcretes tend to be unreliable indicators of actual age because of carbon exchanges during frequent dissolution/precipitation, and adjacent parts of the same horizon can yield dramatically different ages (cf. Gile et al. 1981, Table 22; Monger 1993d, Table VIII-2). This suggests that caution should also be employed in interpretation of stable carbon

isotope signatures from pedogenic carbonates (see Chapter 6.0).

Although calcrete formation can be facilitated by the presence of calcareous parent material, carbonate horizons tend to develop in all profiles with time; even in calcareous materials, the amount of carbonate deposited in the Bk and K horizons usually exceeds the amount leached from the upper solum. This suggests that calcareous dust delivery is a very important mechanism in the formation of calcretes.

5.5.1.4 Clay Translocation and Accumulation

Clay accumulation in the lower solum results in the formation of an argillic horizon that becomes thicker and more clay-rich with time. Argillic horizon development is also a slow process and occurs on a roughly similar timescale as carbonate horizon development. As pedogenesis progresses, arid soils go through an intermediate stage where a cambic B horizon develops. Cambic horizons are subsurface horizons that evince significant alteration from the parent material through obliteration of primary depositional structures, development of incipient soil structure, slight-to-moderate rubification (reddening), some leaching of carbonates, and slight accumulation of translocated clay. Gile (1966b) estimates that distinct cambic horizons can develop in 5,000 years in the vicinity of Fort Bliss, although some aspects (e.g., obliteration of primary structure) can clearly occur more rapidly.

With time, an argillic horizon gradually develops, as clay accumulates to such an extent that a noticeable clay bulge is apparent in a plot of the clay content of each horizon. Clay comprising this bulge can be derived from a number of sources: it can be inherited from the parent material, neoformed in the B horizon through the weathering of silicate minerals, neoformed in the overlying eluvial horizon and translocated down through the profile, translocated from inherited clay in the eluvial horizon, or introduced aerosolically to the soil and translocated to the B horizon. In order to be considered a true argillic horizon, a significant portion of this clay must have been translocated into or within the horizon (Soil Survey Staff 1990).

Translocated clay is indicated by grain coats, intergrain bridges, and laminae of oriented clay in pores and between peds. Argillic horizon development is usually accompanied by increasingly strong development of soil structure as the clay accumulates. In all cases, the argillic horizon develops above the associated carbonate horizon because illuvial clay is typically carried in suspension while carbonate is carried in solution.

However, very strong argillic horizon development can "plug" the horizon, resulting in carbonate precipitation and/or bleaching of sediments above the horizon as infiltration is blocked. Most argillic horizons in semiarid and arid climates are reddened (7.5YR-2.5YR hues) due to oxidation of associated iron and many may be relict remnants of more humid Pleistocene climates (Nettleton et al. 1975).

In all cases, the development of a strong argillic horizon, like a strong carbonate horizon, implies considerable antiquity (i.e., Pleistocene age). Nevertheless, incipient argillic horizons can clearly begin to develop in Holocene timescales. Because the rate of silicate weathering (which is hardly rapid in the first place) is inhibited by low moisture, it is likely that the most important control on argillic horizon development rates in the Fort Bliss region is the rapidity at which eolian processes introduce aerosolic clay.

5.5.1.5 Turbation

Turbation (or pedoturbation) refers to a suite of processes that serve to mix the soil, destroying horizonation. The most common type of mixing, bioturbation, is caused by plants (floralturbation) and animals (faunalturbation). Floralturbation is primarily a function of sediment displacement caused by root growth, although other processes (e.g., tree throw, which occurs when a rooted plant is upended, carrying sediment adhering to the roots up to the surface) can have a local effect. Faunal turbation is primarily a function of burrowing animals (e.g., rodents, insects, earthworms), although mixing of soft surface strata by large animals (e.g., cattle) is also probably significant, particularly in eolian sands. Other mechanisms include argilliturbation (due to heave processes resulting from clay expansion and contraction), cryoturbation (due to heave associated with freezing and thawing), and salt turbation (resulting from growth and dissolution of soluble salt crystals). Although it is a recent phenomenon, another very important source of disturbance on Fort Bliss is vehicular turbation and other forms of disturbance by people.

Turbation processes are particularly important to archeology because mixing of the soil results in disturbance of cultural strata contained within that soil. The degree of disturbance is a function of the type(s) and depths ofurbation processes, and may serve to segregate various size fractions of artifacts; for example,urbation by ants may well result in displacement of small flakes but is less likely to disturb hearth stones significantly, whileurbation by large burrowing rodents can wreak havoc on buried features.

5.5.2 Soil Geomorphology

Soil geomorphology represents an integration of pedology and geomorphology (Birkeland 1974; 1984; 1990; McFadden and Knuepfer 1990). In most cases, soil evidence is used to address geomorphic problems. Birkeland (1990) identifies four typical goals of soil geomorphic research: (1) development of a soil chronosequence framework to date surficial deposits; (2) as indicators of the duration of landscape stability; (3) to examine climate change through the pedogenic effect; and (4) to examine the relationship between soil development, surface hydrology, and hillslope erosion.

Although the disciplines of pedology and geomorphology have essentially developed independently since the early twentieth century, a great deal of convergence has occurred since the publication of Birkeland's landmark book, *Pedology, Weathering, and Geomorphological Research*, in 1974, as researchers have noted that many aspects of geomorphology and pedology are so interrelated that it is impossible to study one without at least some attention to the other (McFadden and Knuepfer 1990). This is well illustrated in the Fort Bliss region, where soils criteria are frequently the only basis for *a priori* estimation of sediment age (see Table 11).

5.5.3 Geoarcheological Implications of Soils and Paleosols

There are four geoarcheological implications of soils and paleosols. First, soil formation implies a

measure of surface stability, particularly in the arid west where the rate of soil formation is strongly governed by the availability of moisture for chemical weathering, organic production, and constituent translocation. Therefore, the presence of a soil within a stratigraphic sequence implies that the surface was neither aggrading or degrading significantly during the period of formation. Archeological components contained within that soil were thus probably exposed at the surface for long periods prior to burial, during which time ample opportunity existed for disturbance processes to affect the spatial (horizontal) arrangements of artifacts within the assemblage. Moreover, because of the length of exposure, the opportunity for organisms to disturb the stratigraphic (vertical) relationships between artifacts in the matrix is also enhanced.

Second, a lack of soil development conversely implies that deposition occurred at a rate greater than pedogenesis, and that the degree of stratigraphic and spatial disturbance due to prolonged surface exposure and pedoturbation are likely to be relatively low. Of course, disturbance due to other factors, such as depositional energy, must be evaluated independently.

Third, where truncated soils are preserved (e.g., where the soil column was eroded to a relatively resistant argillic or calcic horizon), artifacts preserved at or immediately above the erosive contact are likely to be strongly displaced by the erosive energy involved in truncating the soil.

Fourth, where discrete geomorphic surfaces in a given area support similar soils developed in similar parent materials and exhibiting similar relief characteristics, the age of those landforms are likely to be roughly equivalent provided that both have been exposed for similar lengths of time; similarly, where one landform exhibits stronger soil development than another, it is likely to be older unless some factor attenuated pedogenesis on the apparently younger surface. Attenuating factors can include burial by other sediments, followed by exhumation: parent materials with differing resistance to erosion, moisture-delivery

differences, and differences in soil moisture resulting from differing degrees of dissection (Gile 1975a; 1975b).

5.5.4 Soil Geomorphology of Fort Bliss

With the exception of some soils at higher elevations in the Sacramentos and on Otero Mesa, soils on Fort Bliss are essentially identical to soils described in the desert project (Gile and Grossman 1979; Gile et al. 1981). Chronosequences in these soils are well established (Figure 31) and are quite useful for relative dating. Much of the soil sequence has been described previously in this document (cf. Chapter 2.0; Sections 5.1 and 5.2) and will not be repeated here. Rather, the focus of this discussion is on aspects that remain relatively poorly understood, particularly on those aspects with high significance to archeological studies.

The processes and rates ofurbation are one of the least-understood aspects of soil development in southern New Mexico. At the same time, they are one of the most important aspects from a geoarcheological perspective because they represent a major influence on the structure and integrity of buried sites. Although poorly documented, one of the most importanturbation processes appears to be mixing by burrowing insects, particularly termites (Gile 1975b; Abbott 1995). Termites in the area are subterranean and do not form mounds, but do create dense networks of underground passages (Gile 1975b). Abbott (1995) observed that trenches exposing eolian Organ sediments in the bolson frequently appear massive when freshly cut but reveal very dense networks of small insect krotovina when allowed to weather for several days. This fact alone may largely account for the lack of primary stratification typically apparent in Organ-age sediments in the bolson. On the other hand, there is little clear evidence that eolian sediments in the bolson ever contained clear primary strata. If eolian deposition occurred in grassy conditions, disruption of airflow by grasses would tend to inhibit formation of bedding planes. If that is the case, then intensiveurbation does not necessarily

need to be invoked to explain the lack of primary stratification in deposits of Organ age and older.

Larger burrowing animals are also present and large krotovina are occasionally observable in section. If termite burrowing is ubiquitous, then larger burrows should be preserved for only limited spans of time. Large burrows are significant in that they are a possible source of calcrete fragments that occasionally litter the surface of relatively recent eolian deposits and may also displace large buried artifacts. Monger noted that calcrete fragments tend to occur where the calcrete hardpan is within approximately 40 cm of the surface, and postulated that increased wetting and root penetration causes the calcrete hardpan to break up, and that fragments then "begin an upward migration to the land surface" (1993c:35). The mechanism envisioned for this upward migration is not specified, but appears to be some type of heave process. This is somewhat problematic because the clay content of Organ eolian sediments does not appear high enough to explain such a significant incidence of soil heave, nor are freezes intense enough to cause intense cryoturbation. Nevertheless, if such a heave process is active (or has been intermittently active during the Holocene), then the implications for buried sites are profound.

A possible alternative explanation is that burrowing rodents are responsible for the breakup and delivery to the surface of calcrete fragments, and evidence of such large burrows is gradually erased by burrowing insects. If the latter scenario is accurate, then wholesale disturbance of large clasts in the matrix (including those associated with buried archeological features) should be more localized, while disturbance small clasts by termite activity should be ubiquitous.

Another phenomenon noted by Abbott (1995) in the Hueco Bolson is the presence of calcretes that appear to have been exhumed and mechanically abraded. At several alluvial fan sites southeast of Fort Bliss, Abbott noted plugged calcrete horizons developed on fan surfaces of probable Jornada I age that exhibited no upper laminae (as in stage III

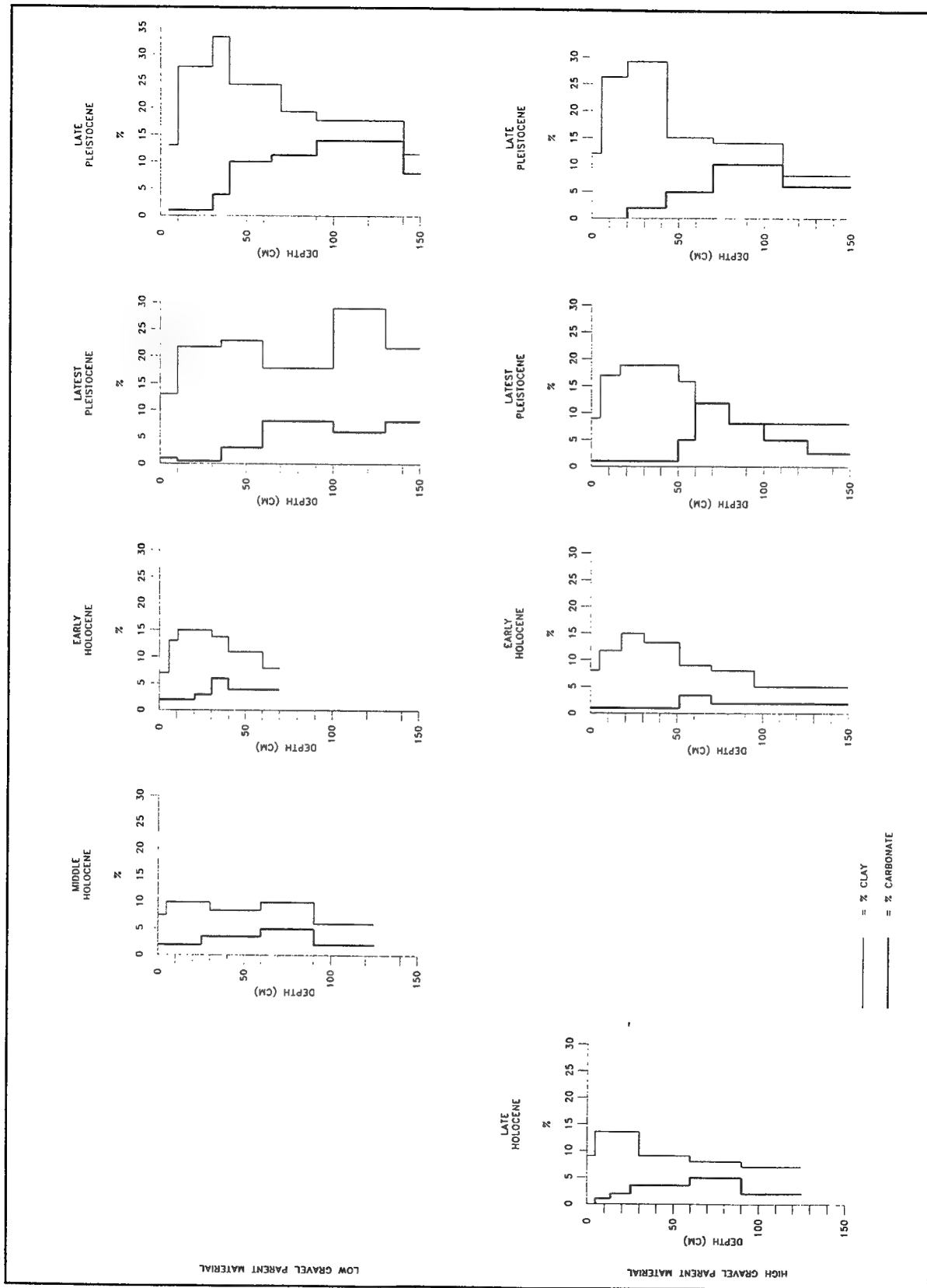


Figure 31 Trends in Carbonate and Clay Content in Alluvial Soils of South-central New Mexico. After Gile et al. 1981.

morphology) but contained vertical cracks coated with thick laminae (typical of late Stage IV-early Stage V morphology). Because these features could not develop without corresponding development of upper laminae, the best explanation is that the calcrete was exhumed and stripped. Overlying sediments in this setting consisted of gravelly loams exhibiting a weak A-Bk profile, suggesting that this exhumation may have corresponded with the regional post-Isaack's Ranch erosion noted by Monger (1993b; 1993e).

The character of soils associated with the alluvial fans, and particularly with desert pavements, is poorly understood. In many cases, the loose pavement on alluvial fans displays evidence of surface disturbance; carbonate pendants, which should be uniformly oriented down and thus not visible, can often be observed on up to 50% of surface clasts. This implies that some mechanism has disturbed the pavements. If this phenomenon is related to euroamerican activity in the bolson (i.e., due to large numbers of cattle introduced in the latter nineteenth century), then surface clasts should show simple pendant morphologies, despite their orientation. If it is due instead to longer-term natural processes, then carbonate coats should be more complex, containing multiple generations of discretely oriented pendants with varying degrees of preservation. Also, the character of soils developed beneath the pavements should provide evidence of the possible applicability of the "born at the surface" model of pavement formation of McFadden et al. (1987).

The degree of A horizon preservation beneath coppice dunes is also relevant. If the coppice fields developed in relatively short order as a result of historic disturbance, then A horizons should be preserved beneath the larger, older coppices. The elevation of these A horizons is also relevant; if the A horizon is preserved at or near the base of the dunes, the degree of interdunal deflation should be low, while if the A horizon is preserved high in the dunes, interdunal deflation would be high, and artifacts in the interdunes are probably reworked from their original contexts.

5.5.5 Research Questions

For the most part, soils provide a suite of tools relevant to addressing other questions on Fort Bliss. A distinct advantage is provided by the proximity of the desert project study area near Las Cruces, which is arguably the most intensive arid-zone soil geomorphology study in the world (see Gile and Grossman 1979; Gile et al. 1981) and provides an excellent framework in which to view the results of observations on soils made at sites on Fort Bliss. Nevertheless, some pressing questions remain.

At each site, the following questions should be addressed:

- 5-58 What is the character of soils developed at the site? How variable are the soil profiles? Is this variability a result of differing depositional units of differing ages, or differential formation rate or degrees of preservation? What are the implications for the age of the sediment? What are the implications for the integrity of sediments at the site?

The following questions are broader in scope:

- 5-59 What are the most important mechanisms of turbation in eolian contexts?
- 5-60 How important are the relative contributions of physical and biotic mechanisms? How common is termite turbation? Rodent turbation? Expansion-contraction due to wetting and drying?

Data needs: Numerous studies of localities and detailed recording of trenches are needed for eolian context, followed by textural and chemical analyses.

The only methods available to assess the degree of mixing of a soil profile are (1) detailed recording of trench profiles, and (2) detailed, targeted analysis of chemical trends (particularly carbonate

content, because insects can be expected to carry finely divided carbonate from the K horizon back up through the profile and leave it unevenly distributed in the profile). Identification of insect krotovina may only be possible if trench faces are allowed to weather for several days. Textural analysis and clay mineralogical studies should permit evaluation of the viability of long term heave due to wetting and drying and salt-crystal growth.

- 5-61 What are the most important mechanisms of turbation in alluvial and alluvial fan contexts? Does disturbance appear to be a recent phenomenon attributable to livestock, or does it appear to have been ongoing? Does the "born at the surface" model of desert pavement (McFadden et al. 1987) formation appear to be locally applicable?

Data needs: Subsurface exposures, detailed profile observations, detailed observations of carbonate coats on individual clasts, and textural and chemical data are needed for alluvial context.

As explained above, the complexity of carbonate pendants on surficial clasts should give an indication of the time depth of surface disturbance on the fan surfaces; simple, randomly oriented pendants would support recent (i.e., livestock) disturbance, while complex, overlapping pendants or pendant remnants on individual clasts would indicate greater time depth. Textural and chemical data would provide a means to address the viability of heave processes, and detailed recording of exposures could assess the ubiquity of biotic disturbance, as described above. The presence of continuous, rock-free zones beneath the pavements would support the McFadden et al. (1987) model of pavement formation, while gravelly sediments would support sheet erosion and deflation as formative mechanisms.

- 5-62 Are A horizons widely preserved beneath the coppice dunes? How much interdunal deflation is indicated, and

what are the implications for archeological strata in the eolian sands?

Data needs: Mechanical exposures are needed through coppice dunes including detailed profile descriptions and elevation observations.

As discussed above, the widespread presence of preserved A horizons would support the hypothesis that the coppice fields are a product of livestock introduction, while an absence would argue against recent origin. If A horizons are preserved, their elevation within the coppice dunes would indicate how great the degree of localized interdunal deflation is. Moreover, the aggregate surface topology of the buried A horizons could indicate how level or rolling the previous landscape was.

- 5-63 Are soils (particularly fine-grained soils) exhibiting moderate Stage II carbonate morphology and incipient argillic horizon development (i.e., Isaack's Ranch soils) preserved on the reservation, and if so, how widely? How widespread are lag strata of carbonate nodules?

Data needs: Abundant subsurface exposures are needed at a wide variety of sites.

Monger (1993b; 1993e) has noted that Isaack's Ranch sediments are commonly represented by a lag of carbonate nodules, implying that a regional deflational episode may have occurred in the early Holocene, prior to onset of Organ sedimentation about 7 ka. This is significant because it implies that all Paleoindian and much Early Archaic material may be out of context, and because it has strong implications for the habitability of the bolson during this time period. If, however, this deflation proves to be localized, then such materials may be locally preserved, and the likelihood for continuity of occupation is enhanced.

5.6 GEOARCHEOLOGY AND CONTEXTUAL INTEGRITY

The lines of inquiry addressed in this chapter are all concerned with the context of archeological

phenomena in the sense employed by Butzer (1982). Butzer defines archeological context as:

...a four-dimensional spatial-temporal matrix that comprises both a cultural environment and a noncultural environment and that can be applied to either a single artifact or to a constellation of sites (1982:4).

and argues for a contextual archeology that:

...will transcend the traditional preoccupation with artifacts and sites in isolation, to arrive at a realistic appreciation of the environmental matrix and of its potential spatial, economic, and social interactions with the subsistence-settlement system (1982:12).

Obviously, the aspects of archeological context addressed here are a subset of those subsumed under Butzer's definition. In particular, the geoarcheological lines of inquiry proposed above are designed to address (1) landscape context, or the configuration of the landscape both at the time of site formation and subsequent to formation, including both the geomorphic configuration and the biotic matrix; (2) depositional context, or the character, depositional agents, and energy conditions represented by sediments that the site is developed in; (3) temporal context of the site; and (4) spatial and stratigraphic context of artifacts and features within the site matrix.

One of the most important aspects of this approach is evaluation of the integrity of an archeological site; that is, the extent to which the three-dimensional distribution of artifacts within the site matrix reflects behavioral processes of the people responsible for that distribution. Artifact distributions are the sum consequence of cultural and natural processes acting on artifacts from the time of initial discard to the time that they are collected by an archeologist. Schiffer (1983; 1987) employs the term *formation processes*, and differentiates between C-transforms (cultural processes) and N-transforms (natural processes).

Binford (1981) has taken strong issue with the concept of C-transforms, arguing that all cultural transforms are reflections of behavior, which is obviously true. Nevertheless, Schiffer's point is well taken; to cite an extreme example, examination of spatial relationships among artifacts in a bulldozed archeological site is likely to tell you much more about the cultural process of bulldozing than the original behavior forming the site. If the goal of the investigation is to understand that original behavior, it follows that subsequent cultural disturbance must be viewed as a filter that does indeed distort the record of interest.

The preceding sections have focused on geological and pedological processes and deposits that affect and structure the archeological record in the vicinity of Fort Bliss; they are essentially a summary of the most important N-transforms affecting the record. Understanding of these processes allows inference about the degree to which the archeological record is distorted by postdepositional factors. Appendix A in this document presents a set of qualitative and quantitative field forms designed to allow field evaluation of the context of archeological sites on Fort Bliss. The basic premise underlying the design of these forms is that the degree of contextual integrity is a very important component of the overall research potential of a site. Thus, sites developed in geomorphic/sedimentologic settings that are generally most conducive to preservation of contextual integrity and sites that exhibit evidence of relative integrity will score higher, while sites developed in unconducive settings or exhibiting evidence of strong disturbance will score lower. Because different portions of a site can frequently encompass different landforms or may exhibit different integrity characteristics, there is a provision to allow definition of two or more subareas within the site boundary where relevant conditions are roughly equivalent.

Determination of contextual integrity is not a simple yes-or-no matter. Rather, it is important to view integrity as a continuum that begins with a

factors associated with the initial formation of the assemblage and proceeds through increasing levels of disorganization (disturbance) to total entropy. As the preceding discussions suggest, the likelihood that a purely behavioral assemblage will be preserved (the "Pompeii premise" of Ascher [1961]) is exceedingly small because postdepositional processes will always have some effect on the preservation and internal spatial relationships of an assemblage. However, the degree to which those processes have altered the spatial relationships between artifacts is highly variable. Thus, an archeological site that has experienced minor spatial and stratigraphic disturbance has a higher information content, and therefore should be considered more valuable than a site that has experienced significant disturbance or has been completely deflated. Yet even these sites have information potential and should be considered more valuable than a heavily bulldozed site or a deflated site whose tool assemblage now rests in a variety of coffee cans in the basements of local collectors.

Although stratigraphic and spatial integrity are desirable, some information can be recovered from sites where that integrity has been lost. However, if that loss of integrity results in the intermingling of more than one component into an inseparable palimpsest, the research potential of the site is sharply reduced. Because individual short-term or long-term behavioral episodes are of primary interest, the quantitative form in Appendix A includes a palimpsest multiplier that allows the score to strongly favor single component sites and multiple components sites where individual components can be isolated on spatial or stratigraphic grounds, while discriminating strongly against sites where multiple components have been hopelessly intermixed. If neither situation can be readily determined, the multiplier is 1 and has no effect.

Finally, it must be pointed out that simple site-by-site evaluation, coupled with overly strict adherence to integrity as a significance criterion, can itself bias the archeological record. Just as resources are patterned on the landscape, the

character geomorphic and sedimentary processes also varies spatially. Moreover, the distribution of resources is in large part governed by the distribution of different landforms and sedimentary environments. Thus, many important aspects of an adaptive system may occur in local environments that are not particularly conducive to preservation, and slavish devotion to integrity as a necessary criterion for significance can lead to the neglect of those sites, skewing perception of the overall adaptive system under study. However, if the evaluation process is structured around geomorphic landscape subdivisions, and integrity criteria applied to each individual site are gauged independently relative to the potential for preservation in each geomorphic environment, then much of this bias can be overcome.

6.0 PALEOENVIRONMENTAL RESEARCH DOMAIN

James T. Abbott

As outlined in Section 2.8, cumulative paleoclimatic evidence from the northern Chihuahuan Desert suggests an essentially unidirectional trend toward aridity throughout the Late Pleistocene and Holocene. However, there is little doubt that finer-grained fluctuations in climatic parameters, such as are suggested by the relatively short dendroclimatological record (cf. Mauldin 1995), were superimposed on this long-term trend throughout the Holocene. Thus, the degree of resolution in the extant data are generally not sufficient to effectively reconstruct environmental changes at a resolution suitable to modeling cultural responses to fine-grained shifts in climate. It follows that more research is needed before the character of the Fort Bliss paleoenvironmental record can be known at a resolution that fully facilitates interpretation of human adaptations to the environment.

The commonly accepted span of human occupation in North America in general, and of the Fort Bliss region in particular, is roughly the last 12,500 years (latest Pleistocene to the present); therefore, the focus of proposed research is on this period. However, not all scientists are agreed that this range is accurate, and one of the most important sites advanced as evidence of Pleistocene occupation in North America is on Fort Bliss (Pendejo Cave, excavated by R. S. MacNeish)(Appenzeller 1992). For this reason, and because historical context is also important in understanding trajectories of environmental change, archeologically sponsored paleoenvironmental research on Fort Bliss should not focus exclusively on the period beginning in Paleoindian times, but should instead embrace the whole of the late Quaternary.

6.1 NATURE OF THE EVIDENCE

Four basic lines of evidence can be exploited to examine the environmental history of a region:

historical data, circulation models, proxy evidence, and direct evidence.

6.1.1 Historical Evidence

The best, and at the same time most limited, source of data are historical records that document then-current climatic and environmental conditions. These records can provide both direct data on climate (e.g., temperature, precipitation, winds, humidity) and on environmental conditions (e.g., vegetation observations, stream flow, channel incision and migration, dune formation), and may occur in the form of either written or photographic records. In general, the resolution provided by these types of data is far superior to that obtained from proxy sources; however, the timespan covered is so limited that they are frequently good for little more than providing a comparable modern baseline.

6.1.2 Global Circulation Models

Global circulation models provide a type of information on climate change that is complimentary to empirical methods by conceptually addressing the root causes, rather than examining the effects, of shifts in temperature and precipitation patterns through time (Kutzbach 1983; Kutzbach et al. 1993; Bryson et al. 1970). Global circulation models can also provide additional types of data, such as characteristic wind speeds and directions at various times of year, that are very difficult or impossible to obtain from proxy evidence. These computer models simulate atmospheric behavior by considering the complex interaction of atmospheric, terrestrial, and oceanic processes. Boundary conditions for the models are in turn based on geological evidence for a variety of parameters such as sea-surface temperature, terrestrial and ocean ice volume, orographic influences imposed by topographic variability, and the composition of atmospheric aerosols and gasses (Kutzbach 1983; Kutzbach and Ruddiman 1993).

6.1.3 Proxy Evidence

Many lines of paleoenvironmental information involve proxy evidence, which allows indirect examination of one environmental variable through its effects on other variables. Because they are dynamically interrelated, a single type of data can provide direct evidence about one aspect of the former environment (e.g., macrobotanical evidence of vegetation) and, simultaneously, indirect proxy evidence about another aspect (e.g., the climatic parameters indicated by the presence of those biotic taxa). Most proxy evidence bears on paleoclimatic questions through examination of other systems, such as vegetation or soils; however, proxy evidence can address issues other than climate (e.g., evidence of the composition of biota derived from stable isotope analysis of soil carbonate).

Few lines of proxy evidence have been exploited in detail in the Fort Bliss region, although some work has been done on most of the major categories. As a result, the paleoenvironmental picture is starting to come into focus, but much work needs to be done before the remaining questions can be resolved. The major classes of proxy climatic evidence relevant to the Fort Bliss region, and examples of studies utilizing these data from southern New Mexico, west Texas, and surrounding regions, are presented in Table 13. The potential resolution and scale of these approaches differ markedly; for example, while tree rings can provide an extremely high-resolution record, their time depth is limited, while other methods such as geomorphic criteria, pollen, and isotope evidence can provide a much longer record but at a lower degree of temporal resolution. Because proxy evidence represents environmental response to climatic shifts, interpretation requires compensation for the effects of the intervening physical and biological processes, variable lag times, and local versus regional effects. Consideration must also be given to the depth of abstraction; in other words, the distance of the evidence from the characteristic being considered. For example, in the example presented above where stable isotopes are used to address the

composition of the biotic assemblage, it is then possible to infer climatic conditions from that assemblage. Although such applications are routinely pursued, they represent an additional layer of abstraction, with a whole other set of requisite assumptions, and require even greater caution in interpretation.

One of the principal problems inherent in the use of proxy data for paleoclimatic reconstruction is the concept of equifinality (i.e., the realization that a shift from condition A to condition B in a physical or biotic system can be stimulated by a variety of different environmental changes) (Bull 1991). For example, if a biotic change is noted at a certain time (e.g., piñon pine disappears from an area), it is not immediately clear whether it is due to a shift in precipitation influx or temperature because the interaction between these two variables controls the amount of moisture available for plant growth and changes in either or both may be responsible (Thompson et al. 1993). Similarly, a given geomorphic response (e.g., stream incision) can result from changes in annual precipitation, precipitation timing and/or intensity, or sediment yield (Schumm 1977).

Another problem with proxy evidence is that various physical and biotic systems have different levels of sensitivity to perturbations in climate. Thus, threshold conditions necessary to initiate change in the various systems may not be exceeded simultaneously, or at all. For example, a decrease in effective moisture may have the effect of reducing the density of groundcover to the extent that geomorphic changes are initiated without seriously affecting species composition in the vegetation community; thus, while the geomorphic system changes in a manner reflected in the stratigraphic record, evidence of vegetation change in the pollen and macrobotanical records may be absent. Lag times may also differ, such that a noticeable change in one system may occur much more quickly than in other, related systems. Thus, uncritical interpretation of the timing and character of climatic change can be expected to differ depending on the evidence considered. Also, a single environmental stimuli may initiate a

Table 13 Types of Proxy Data Bearing on Climate, with Representative Studies.

| Category | Source | Relevant and Example Studies & Syntheses | |
|---------------------------|--------------------------|---|---|
| Biotic Evidence | Macrofossils | Wells 1966; Van Devender et al. 1984; Van Devender 1990 | |
| | Plants | Pollen | Freeman 1972; Markgraf et al. 1984; Leopold et al. 1963; Hall 1990; Gish 1993 |
| | | Phytoliths | Buck 1993; Scott Cummings 1963 |
| | | Diatoms | <i>Winsborough 1994; Bradbury 1984</i> |
| | | Dendroclimatology | Mauldin 1995; Drew 1972; Dean and Robinson 1978 |
| | | Large Fauna | <i>Dillehay 1972</i> |
| | Animals | Microfauna | Harris 1989; 1990 |
| | | Insects | Elias and Van Devender 1990; 1992 |
| | | Gastropods | <i>Neck 1987</i> |
| | | Ostracods | <i>Delorme 1989</i> |
| | | Isotope Chemistry | Huebner 1991a |
| | | Humans | Isotope Chemistry |
| Coprolites | Bryant 1974; Bohrer 1981 | | |
| Dentition & Skeletal data | Marks et al. 1985 | | |
| Soil Evidence | Soils | Morphology and Development | Monger et al. 1993; Gile et al 1979; 1981; Gile 1966 |
| | | Isotope Chemistry | Monger et al. 1993; Rightmire 1967 |
| Geological Evidence | Sediments | Alluvial stratigraphy and sedimentology | Ruhe 1964; 1967; Gile et al. 1979; 1981 |
| | | Eolian stratigraphy | Monger 1993; Blair et al. 1990 |
| | | Timing and character of slope activity | <i>Bull 1991</i> |
| | | Lake/Playa Sediments and shoreline features | Khresat 1993; Reeves 1965 |
| | | Tufa and Speleothem Formation | <i>Szabo 1990</i> |
| Historical Records | Direct climate records | U. S. Weather Bureau Files | |
| | Vegetation records | Buffington and Herbel 1965; York and Dick-Peddie 1969 | |

Studies listed in italicized type have little or no local relevance and are included as illustrations of the method only.

sequence of successive, differing systemic adjustments to the new equilibrium conditions (Chorley and Kennedy 1971). For example, a change in moisture influx may cause an initial increase in sediment delivery to a stream ill-

equipped to transport it effectively, causing aggradation in the upper basin. With time, however, the stream will adjust its channel geometry and gradient in the upper basin to carry the increased load, incising into the newly formed

deposits. However, this adjustment may increase delivery to the lower basin, causing it to aggrade in turn. Thus, a single impulse at time X may result in a sequence of successive, time-transgressive aggradational and incisional events that affect various parts of the basin for decades or centuries that follow in a process termed complex response (Schumm 1973; 1977). Uncritical examination of such a record could easily lead to an erroneous interpretation that identifies a number of changes in climate, when in reality the sequence reflects successive adjustment to a single climatic stimulus.

Climatic changes may also be manifest in a number of different ways. While many treatments tend to simplify the relationship to questions of variability in temperature and moisture on an annual basis, climate changes can also occur as shifts in the timing and/or intensity of precipitation and in seasonal temperatures. These changes may strongly affect some systems without affecting others. For example, a shift from a dominance of gentle, winter precipitation toward intense summer precipitation could conceivably have a strong impact on vegetation without significantly affecting annual precipitation totals. If temperature remained constant, such a change would decrease effective soil moisture on an annual basis, moving the biotic community toward a more arid-adapted composition. Thus, a net systemic effect interpreted as a move toward aridity could arise without a change in annual precipitation totals. If, instead, the aforementioned shift in precipitation timing was accompanied by changes in average summer or winter temperatures, then the net tendency toward increased arid adaptation in the biotic assemblage could be increased, ameliorated, or reversed, depending on the magnitude, direction, and timing of temperature shifts. However, geomorphic systems could still be expected to respond to the change in precipitation intensity and timing.

Another factor to consider in examination of the effects of climate change is the preexisting state of various physical systems. For example, depending on the density of vegetation cover at the time of a

shift toward increased precipitation, the net result could be either a decrease in sediment production (as vegetation density increases under the influence of more effective moisture) or an increase in sediment production (as unprotected sediment on the slopes is subjected to more frequent or intense storms). To cite another example, there is good reason to believe that the historic changes in the character of the basin floor (e.g., replacement of grasses by scrub vegetation, formation of the coppice dunefields) occurred primarily because the former grassy ecosystem was already in a precarious, marginal state of equilibrium with the climate, and the historic disturbance probably would have had a far different effect if the system had been more stable (York and Dick-Peddie 1969).

In short, landscape responses to climatic changes are complex and reflect the interaction of a number of related biotic and physical systems. For this reason, paleoclimatic interpretations derived from proxy data are typically far from straightforward, and multiple lines of evidence are highly desirable.

6.1.4 Direct Evidence

Many lines of proxy evidence are also lines of direct evidence when considered in a different light. Many forms of paleovegetation information (e.g., macrobotanicals, pollen) can be considered direct evidence of vegetation presence, while simultaneously serving as proxy evidence of climatic conditions. Other types of evidence (e.g., oxygen isotopes, lake levels, tree rings) are sometimes considered as direct evidence of climatic conditions. However, it is important to realize that even direct evidence is affected by various processes that filter the data, requiring considerable interpretation to arrive at paleoenvironmental significance. For example, while macrobotanicals and pollen do provide direct evidence that specific species were present, either locally (in the case of macrobotanicals) or within the range of aerosolic transport (in the case of pollen), they require many assumptions about and adjustments for natural filters that affect the data before a picture of the local paleovegetation

assemblage can be obtained. Similarly, while oxygen isotopes do reflect water temperature, it is not immediately clear whether trends reflect changes in mean annual temperature, changes in the seasonality of precipitation (winter precipitation is, naturally, colder than summer precipitation, and therefore should have a different isotopic signature), or changes in the moisture source (e.g., warm Gulf versus cold Pacific moisture) that are only tangentially related to actual temperature trends. Lake levels, too, may reflect either increases in precipitation or decreases in temperature (which reduce effective evapotranspiration), while the response of tree rings to regional climatic shifts is also strongly conditioned by microclimatic, edaphic, and biological factors.

The preceding examples are not a complete list of data types that could be considered direct lines of paleoenvironmental evidence. However, they do illustrate the salient point, that no matter what the evidence is, at least some level of abstraction is necessary to arrive at meaningful interpretation of the data, and some of the assumptions and/or weightings given to various aspects of the filtering mechanisms are apt to be wrong. Thus, multiple lines of evidence are crucial to robust paleoenvironmental reconstruction.

6.2 DIRECT AND PROXY SOURCES OF PALEOENVIRONMENTAL INFORMATION

The following sections briefly summarize the most important individual lines of evidence that have the potential to inform on the trajectory of climate change in the Fort Bliss region through the late Quaternary. The emphasis of this discussion is on potential contributions; extant results are summarized in Section 6.3.

6.2.1 Macrobotanical Information

Macrobotanicals consist of the remains of plant tissue. Because different plants have unique and distinctive cellular structures and produce distinctive seeds, microscopic and sometimes macroscopic examination can be used to document

that a particular taxon was present; dating of the remains or associated materials allows for a statement of the time frame represented. Preservation of ancient plant tissues is usually a result of one of three processes: incomplete combustion, which carbonizes the remains, thus allowing them to resist decomposition; dessication, which inhibits microbial activity; and anaerobic saturation, which also limits microbial decomposition. Naturally, because of the arid climate, only the former two mechanisms should be expected to occur on Fort Bliss.

Because different plants have varying tolerances for extremes in temperature and precipitation, examination of representative plant assemblages can be used to reconstruct the character of the environment through the use of modern analogs. Unfortunately, the process is complicated and requires a number of assumptions be made before an environmental interpretation can be obtained. First, the modern range of the taxon must be known and the limiting environmental factors must be understood. Second, the taxon must be in equilibrium with its modern range. Third, the fossil remains must represent taxa that were also in equilibrium with environmental variables. Fourth, the modern range must be a reflection only of environmental tolerances; other factors such as interspecies competition cannot be limiting factors. Finally, the ecological affinities of the taxon must not have changed with time.

In practice, it is impossible to know with any degree of certainty whether any of these assumptions are true. Further complicating matters, few interpretations can afford to focus on a single type of organism, nor should they. Different organisms living with the same modern range of environmental conditions are said to be sympatric. If the fossil remains reflect a sympatric assemblage, then interpretation is strengthened. Unfortunately, many fossil assemblages are disjunct, meaning that they are composed of various taxa that do not now occupy the same environment, which greatly complicates interpretation because no modern analog exists. Nevertheless, examination of biotic records

provides one of the most powerful suites of tools for examination of the paleoenvironment.

The most comprehensive work in the Chihuahuan Desert region concerns examination of fossil packrat middens (and occasionally middens of other animals, such as porcupine), which have yielded macrobotanical, microfaunal, insect faunal, and occasionally pollen evidence of local environmental conditions through time (e.g., Wells 1966; Van Devender and Spaulding 1979; Van Devender et al. 1984; Van Devender 1990; Elias and Van Devender 1990; 1992). In addition to packrat middens, macrobotanical information can occasionally be obtained from archeological sites, particularly if the plant tissue was partially carbonized in a fire. In this context, the recovered material typically represents something of economic value (e.g., foodstuff, fuel) that was intentionally carried to the site by people; it is entirely possible that the material is not at all representative of the local environment because people can and often do carry specific resources for long distances. Thus, while carefully interpreted macrobotanical assemblages from archeological contexts can provide a tremendous amount of information about subsistence, seasonality, and (potentially) mobility and procurement patterns, they should usually be viewed with caution in characterization of the local environment.

6.2.2 Pollen and Phytoliths

Pollen, and to a lesser extent phytoliths, can also provide a picture of the vegetation assemblage in a given region at various points in time. Pollen grains are microscopic structures dispersed in great numbers by higher plants (angiosperms and gymnosperms) that carry male genetic material to other plants, enabling reproduction. While some taxa (mainly flowering plants) are dependent on insects to carry the pollen between plants, many plants simply produce and release great numbers of airborne pollen, literally casting their fate to the wind. Pollen grains of different plants are distinctive structures with characteristic shapes and features, and only one type of grain morphology is

produced by an individual taxon; consequently, examination of pollen allows determinations of which parent plant taxa are represented.

Phytoliths are tiny siliceous structures formed by the precipitation of dissolved silica in and around cells in plants. They are most common in plant tissues where evapotranspiration is highest, particularly in leaves, and develop distinctive shapes that mirror the sites of deposition (e.g., internal cellular and intracellular casts). On death of the plant, phytoliths are released into the environment through decomposition, where they behave as any other similarly sized sediment. Phytoliths range in size from less than 1 micron (coarse clay-sized) to more than 500 microns (medium sand-sized), with most identifiable types measuring less than 50 microns (silt sized) (Buck 1993). Because they are composed of opaline silica, phytoliths are very resistant to degradation under most surface conditions. Because different plant taxa have distinctively sized and shaped cells, phytoliths have the potential to allow identification of the parent plant, and thus allow for paleoenvironmental reconstruction (Rovner 1971). However, the fact that many different sizes and shapes of phytoliths can be generated by a single plant taxon--indeed, by a single plant--has greatly complicated classification and generation of phytolith taxonomies, which are a necessary step if they are ever to be broadly applicable to paleoenvironmental problems.

At present, the applicability of pollen analysis is much greater than that of phytoliths for several reasons, including: (1) pollen grains produced by a given taxon are essentially identical, while phytoliths can exhibit extremely variable morphology; (2) pollen grains are much easier to extract in a sediment sample because they generally have different density characteristics than the sediment, while phytoliths do not; and (3) pollen taxonomy is much better developed than phytolith taxonomy. Nevertheless, phytolith studies have shown some promise, particularly in the identification of broad classes of relatively simple plants like C³ and C⁴ grasses (Twiss 1987; Scott Cummings 1993).

Despite its advantage, pollen analysis is extremely complex and problematic. Deriving a representative picture of regional vegetation from a pollen sequence requires (1) preservation of pollen, which in itself is no mean feat in the harsh, oxidizing environment of the Fort Bliss region; (2) compensation for the effects of differential transport of various pollen grain taxa, some of which can be carried hundreds of miles by wind; (3) compensation for the effects of differential pollen production by various taxa; and (4) compensation for differential pollen preservation, which occurs because various pollen taxa have differing resistance to environmental corrosion.

Although some successful pollen research has been conducted in south-central New Mexico (e.g., Hall 1990b; Markgraf et al. 1984), pollen preservation is generally not good in the region. However, there is still some potential, particularly if sediments are preserved in the playa lakes (Oldfield and Schoenwetter 1975). Phytolith analysis (e.g., Buck 1993; Scott Cummings 1993) is in its infancy and has yielded little informative data to this point. However, the resiliency of phytoliths in the environment is much better than pollen, and therefore merit continued attempts to refine their method and classification.

6.2.3 Tree Rings

The application of tree rings to paleoclimatic problems, termed dendroclimatology, is based on the fact that tree growth is frequently limited by climatic parameters. As a tree grows, annual cycles of growth are reflected by successive annuli of thin-celled, high growth-season wood, and dense, thick-celled, low growth-season wood. As early as the eighteenth century, it was recognized that tree rings could vary in width in response to annual levels of environmental stress, and thus represented a proxy record of climatic conditions (Bradley 1985). Subsequent work (e.g., Douglas 1919; Fritts 1976) has established that tree rings can indeed provide a sensitive, albeit complex, proxy record of paleoclimatic conditions.

The use of tree rings as paleoclimatic indicators is complicated by a number of factors. Trees are biotic organisms with complex responses to environmental stimuli. Many trees, especially ones that are able to exploit groundwater, are relatively immune to minor climatic perturbations, and exhibit relatively uniform widths (complacent tree rings) that have little relation to climate. However, the growth of other trees is strongly conditioned by climate (sensitive tree rings) and contains a clear climatic signal contained in the widths of annular rings.

Another complication is introduced by the fact that, as a tree grows and its girth increases, the width of individual rings decreases. Therefore, in order to obtain a climate record from an individual tree's rings, or to correlate between trees of different ages to extend a chronology back in time, it is first necessary to standardize tree ring widths by fitting them to a polynomial growth curve, which is a complex procedure and requires a number of assumptions (see Bradley 1985 and Fritts 1976). Once the record is standardized, it must then be calibrated to climatic parameters controlling growth before independent climatic statements can be made. This procedure is even more complex, and is usually accomplished with multivariate regression statistics (Fritts 1962; 1976; Bradley 1985).

In addition to widths, density characteristics of wood composing individual rings are also somewhat dependent on climate and thus can provide a paleoclimatic signal (Schweingruber et al. 1979). Finally, isotopic analysis of oxygen ($^{18}\text{O}/^{16}\text{O}$) and hydrogen (deuterium/hydrogen) contained in cellulose of tree rings can provide a sensitive record of temperature variations (Bradley 1985; see Section 6.2.6), although other factors can also complicate this signal (Luckman and Gray 1990). The most sensitive and robust reconstructions combine width, density, and isotopic data, and can yield very sensitive records of paleoclimatic conditions (Bradley 1985).

6.2.4 Diatoms

Diatoms are a type of algae whose cellular contents are enclosed between two valves of framework silica that is preserved when the organism dies. Diatoms can occur in remarkable abundance (up to 4,000 living organisms per milliliter of water and up to 200 million per cubic centimeter of lakebottom sediment), rendering them relatively easy to come by in both extant and fossil lake deposits (Bradbury 1988). The paleoenvironmental significance of diatoms arises from the fact that different taxa have differing tolerances for extremes of temperature, salinity, water depth, water clarity, and lake eutrophy (nutrient concentration), and respond rapidly to changes in these factors.

The same types of problems inherent in pollen analysis are also present in diatoms. Different taxa are differentially susceptible to destruction and adverse chemical conditions can impose a taphonomic bias on the record. Diatoms are also highly subject to transport within water bodies and are readily reworked from older sediments that may reflect different climatic conditions. Also, the controlling environmental parameters are sometimes problematic; although commonly interpreted as temperature indicators, some work (e.g., Brugham 1980) has suggested that many diatoms have wide temperature tolerance and are primarily sensitive to changes in water chemistry and lake eutrophy. Nevertheless, examination of trends in diatom taxa through time in lake-bottom sediments can provide a high resolution picture of changes in conditions resulting from shifts in water influx and evaporation rates, particularly when combined with other types of data (e.g., ostracodes, pollen) (Bradbury 1984; 1988).

6.2.5 Fauna

A variety of types of fauna can provide paleoenvironmental information. Like plants, different animal taxa are adapted to exploit specific environmental niches; thus, changes in climate and accompanying changes in environmental conditions dictate the geographic range in which the fauna

will live. Thus, the presence of taxa with known modern environmental tolerances and geographic ranges can be used to infer the character of previous environmental conditions. However, as with plants, the interpretation of fossil animal assemblages also requires assumptions about the degree to which the ancient remains and the modern analogs are in environmental equilibrium and represent stable ecological preferences (see Section 6.2.1); taphonomic biases are also of considerable concern. Many of these assumptions are dangerous because the short life cycle of the smaller, more environmentally sensitive animals (particularly micromammals) renders them relatively well suited to rapid adjustment to different environmental conditions. Further, reconstruction of past climatic conditions is best accomplished with species that show relatively strong sensitivity to climatic parameters; many species are adapted to a wide range of environmental conditions and are therefore less useful indicators of past environments.

Nevertheless, animal remains can provide considerable paleoenvironmental information. Arthropods, for instance, have been utilized extensively. Many types of insects, arachnids, and chilopods have been found in Quaternary deposits in the Fort Bliss region. Elias and Van Devender (1992) report that 101 taxa of insects, arachnids, and chilopods have been recovered from fossil contexts in the vicinity of Fort Bliss. These insects, and Coleoptera (beetles) in particular, have proven a valuable source of paleoenvironmental data in the Fort Bliss region (see Section 6.3).

Gastropods (particularly land snails) are another potential source of paleoenvironmental information that has yet to be exploited to any degree in south-central New Mexico. Like other small animals, gastropods have specific microenvironmental preferences and can provide a sensitive record of minor environmental shifts (Neck 1987). Identification of taxa is accomplished on the basis of shape and surface relief and is relatively straightforward in comparison to other types of invertebrate evidence because the number of different taxa in an area is usually limited and

taxonomies are typically well developed (Lowe and Walker 1994).

Ostracods are tiny, aquatic arthropods composed of a hinged outer shell, or carapace, that protects the soft body parts inside. These carapaces are frequently preserved in alluvial and lacustrine sediments, and contain a wide variety of diagnostic features (e.g., frills and spines, muscle scars, pore canals) that allow species differentiation (Lowe and Walker 1984). Different taxa of ostracods are adapted to specific, frequently narrow extremes of water temperature and salinity; freshwater species are also strongly controlled by the character of the substrate. Because ostracods (as a class) can live under a wide range of temperature conditions, and in fresh to hypersaline water, the proportions of ostracod species are a direct reflection of water temperature and salinity; individual species are indicators of minimum and maximum temperatures (Delorme 1989). Thus, analysis of ostracod assemblages at a given locality, and their changes through time, can provide abundant information about local water conditions, and thus allow inferences about broader paleoenvironmental trends.

Although most vertebrates can also be used to provide paleoenvironmental information, investigation tends to focus on mammals, and particularly micromammals (e.g., shrews, voles, gophers) because they are typically the most highly specialized, and thus provide the tightest constraints on accompanying environmental conditions (Graham 1987; Lundelius 1986). Although the controls on small mammal distributions are often a direct consequence of climatic parameters, they sometimes reflect other characteristics of the environment. For example, Semken (1961) and Toomey (1993) document the disappearance of the plains pocket gopher (*Geomys bursarius*) from central and west-central Texas during the Holocene, and relate that disappearance with widespread soil erosion that essentially destroyed its habitat.

Although larger animals are generally more tolerant of extremes in temperature and

precipitation, and thus provide less sensitive evidence about former conditions, they can also sometimes provide valuable evidence of environmental conditions. One important distinction is between browsers (e.g., deer), which are primarily dependent on leafy vegetation, and grazers (e.g., pronghorn), which depend primarily on grasses. Because of these differing diets, the relative frequency of browsing and grazing animals can be used as a rough proxy of the character of the biotic assemblage. Bison population changes are also commonly interpreted as evidence of environmental changes (Dillehay 1974), although various researchers have differed strongly on the climatic implications of these shifts (cf. Hall 1982; Dillehay 1974; Creel et al. 1990).

6.2.6 Stable Isotopes

Stable carbon isotopes provide another avenue of paleoenvironmental information. Isotopic investigation can provide clues to the character of vegetation, diet, and temperature in the prehistoric environment. Commonly investigated isotopes include ^{13}C , ^{18}O , and ^{15}N .

As rainwater passes through the solum of a soil, it takes on the isotopic character of soil CO_2 , which is a function of plants growing on the surface. Carbon occurs in three basic isotopic forms: ^{14}C , which is radioactive and forms the basis of radiocarbon dating, and ^{12}C and ^{13}C , which are both isotopically stable. In sum, roughly 98.9% of the carbon in circulation is ^{12}C , 1.1% is ^{13}C , and $1.18 \times 10^{-10}\%$ is ^{14}C (Lowe and Walker 1984). However, biological processes tend to fractionate ^{12}C and ^{13}C such that the ratio between the two reflects the metabolic pathway of the organism that fixed the carbon into its structure. Three different metabolic pathways are recognized in plants: the Calvin-Benson pathway (CAL or C_3) pathway, which is typical of most plants (including almost all plants in the temperate regions) and has a typical fractionation of approximately -22‰ to -33‰; the Hatch-Slack (HS or C_4) pathway, which is typical of tropical grasses (including some grain crops) and has a typical fractionation of -9‰ to -16‰; and the CAM (crassulacean acid metabolism)

pathway, which utilizes both of the other pathways depending on temperature and photoperiod, has intermediate fractionation values, and is typical of succulents like cactus (van der Merwe 1982; DeNiro 1987). Stable carbon isotope analysis of faunal (Schoeninger and DeNiro 1984) and human (Huebner 1991a; DeNiro 1987) remains has demonstrated that $\delta^{13}\text{C}$ values reflect the composition of paleodiet, with uniform shifts reflecting trophic level. In the southern Plains and Rockies, a great deal of attention rests on systematic variation in $\delta^{13}\text{C}$ of values that reflects climate-driven shifts in the relative abundance of C-3 and C-4 plants. In addition to studies of bone from animals feeding on the plant assemblage, this variability is reflected in the isotopic composition of soils and sediments supporting the vegetative community (e.g., Nordt et al. 1994; Amundson et al. 1988) and in pedogenic carbonates developed in those soils (Cerling 1984; Monger 1993d; Monger et al. 1993). Stable carbon isotopes have also been extracted from occluded carbon in opal phytoliths (e.g., Kelly et al. 1991), which provides a record of isotopic composition of individual plants that lived in the system.

Systematic, temperature-dependent variation in the fractionation of the $^{18}\text{O}/^{16}\text{O}$ isotopes of oxygen was initially recognized by Urey (1947), and was subsequently used to calculate variations in global temperature based on the isotopic composition of deep-ocean sediments (Emeliani 1955). However, subsequent workers (e.g., Shackleton 1967; Dansgaard and Tauber 1969; Shackleton and Opdyke 1973) have argued that most of the observed changes in oxygen isotope composition are due not to temperature changes *sensu stricto*, but rather to changes in global ice volume. The basic argument is that during evaporation of seawater, a natural fractionation occurs as the lighter ^{16}O isotope is preferentially evaporated, rendering atmospheric water vapor isotopically lighter than the water in the oceans. During glacial periods, this isotopically light water vapor is subsequently bound up in the continental ice sheets, resulting in progressive enrichment of the ocean reservoir in the heavier ^{18}O isotope, while

deglaciation frees the trapped lighter isotopes, which are returned to the sea in meltwater.

In terrestrial situations, oxygen isotopes do have a direct, albeit complex, relationship to temperature variations. For the same reason that isotopically light water (molecules containing ^{16}O) is preferentially evaporated, the concentration of isotopically heavy water (molecules containing ^{18}O) in precipitation is a function of temperature. However, this record is far from straightforward, as the isotopic composition of an air mass is affected by a number of factors, including (1) the isotopic composition of the moisture source(s), (2) exchanges between water vapor and water droplets in the air, as well as with water on the ground, (3) the amount of moisture in the air relative to its original water content, (4) the kinematics of precipitation, (5) the temperature at the source, (6) distance from the source, and (7) the latitude of the source and study areas. Nevertheless, the $\delta^{18}\text{O}/^{16}\text{O}$ ratio terrestrial deposits have been successfully used to obtain analog records of paleoclimatic variation from a number of sources, including glacial ice (e.g., Paterson et al. 1977; Epstein et al. 1970), tufas and travertines (Pazdur et al. 1988), sedimentary and chemical lacustrine deposits (Müller and Wagner 1978; Abel et al. 1982), pedogenic carbonates (Allan and Matthews 1982; Magaritz 1983), and cave speleothems (e.g., Harmon et al. 1977; Thompson et al. 1976). Biotic remains (e.g., wood, snail shell, bone) also contain an oxygen isotope record, but interpretation is very difficult because of the additional complexities introduced by metabolic fractionation; nevertheless, such materials can also provide valuable paleoenvironmental information (e.g., Jacoby 1980; Gray and Thompson 1976).

Finally, nitrogen isotopes can be used to differentiate between nitrogen-fixing plants (legumes) and other plants. While most plants can only obtain nitrogen from soil nitrates and ammonium, legumes (or rather, bacteria that live in a symbiotic relationship with legumes) are able to also extract N_2 directly from the atmosphere. Because the atmosphere is not enriched in ^{15}N , and soil nitrates and ammonium are, leguminous plants

typically exhibit much lower $\delta^{15}\text{N}$ (approximately 1‰), while nonlegumes are closer to 9‰ (DeNiro 1987). As the plants are consumed and metabolized, $\delta^{15}\text{N}$ is enriched approximately 3‰ for each trophic level (Bousman 1990). Another relatively poorly understood phenomenon is that the $\delta^{15}\text{N}$ in plants and animals also appears to increase in response to elevated aridity and salinity in the environment (Heaton 1987; Sealy et al. 1987), suggesting that systematic variation in $\delta^{15}\text{N}$ could be used as a proxy for patterns in precipitation.

6.2.7 Human Skeletal Remains and Coprolites

Human skeletal remains can provide a number of lines of evidence relevant to paleoenvironmental and subsistence questions. Bones and teeth can retain physical evidence of a variety of pathological conditions, many of which are linked to specific or generalized dietary deficiencies (Brothwell 1965; Buikstra and Ubelaker 1994). Isotopic studies (e.g., Sr/Ca, Ba/Sr, stable carbon, stable nitrogen) can provide considerable detail about dietary habits (Buikstra and Ubelaker 1994), which in turn has implications for the character of the available resource base. However, the use of skeletal remains for such purposes is complicated by a number of ethical and legal ramifications that are beyond the scope of this discussion. Human coprolites, which are dessicated feces, can also be used to address dietary questions in a uniquely direct, albeit short-term manner.

6.2.8 Soil Morphology

Soil criteria can provide valuable evidence of previous climatic conditions because the types and rates of pedogenic processes, and therefore the resulting thickness and morphology of soils, are strongly controlled by climate. As discussed in Section 5.5, there is good reason to believe that many of the more strongly developed soils in the Fort Bliss region are actually the result of previous climatic conditions and would not develop to such a degree under the present climate in any length of time. However, the character of soils is not a precision method to reconstruct paleoenvironment

and is probably one of the least useful tools available to address extant paleoenvironmental problems in the Fort Bliss region.

6.2.9 Stratigraphy and Sedimentology

The character of sediments and landforms developed under particular climatic regimes is frequently a valuable tool for understanding the character of former environments. The types and morphologies of landforms themselves are in large part dictated by environmental characteristics (Büdel 1983; Bull 1991), and the types of sediments laid down are strongly indicative of their environment (Reineck and Singh 1980). The climatic implications of various landforms and sediments in the Fort Bliss area have been addressed in Chapter 5.0; the reader is referred there and to references cited therein for detailed treatments on the climatic implications of sediments and landforms.

6.2.10 Tufa and Speleothems

Tufa and travertine deposits represent chemically precipitated calcium carbonate that form around springs, seeps, in stream channels, in caves, and occasionally on the margin of lakes. Because the deposits can sometimes accrete relatively rapidly, they have considerable potential utility for paleoenvironmental studies. Speleothems are travertine deposits that form in deep caves, where changes in ambient environmental conditions occur relatively slowly. Although they have distinct advantages over deposits formed in more open conditions, particularly for isotopic studies, accretion of speleothems is frequently too slow to provide a high-resolution Holocene record.

Travertine consists of dense, thin-laminated to microlaminated carbonate, while tufa typically has a spongy to vesicular structure (Bates and Jackson 1984). Much of the spongy structure of tufa appears to result from accretion in and around a mat of algae or bacteria, which can in fact chemically stimulate the precipitation of the carbonate. In rockshelters, the formation of tufa and travertine implies active groundwater

discharge, and suggests that the rate of accretion should vary as a function of changes in regional precipitation. This general relationship has been confirmed by a number of researchers working at significantly longer time scales (e.g., Harmon et al. 1977; Gordon et al. 1989; Szabo 1990). Thus, changes in the rate of travertine accumulation may provide a sensitive indicator of changes in precipitation rates throughout the Holocene, providing that the travertine sequence can be dated.

Several other lines of paleoenvironmental information are also potentially obtainable from travertine deposits, including paleotemperature information provided by the analysis of the isotopic oxygen, and paleovegetation analysis provided by isotopic carbon and nitrogen. However, most authors (e.g., Bradley 1985, Lowe and Walker 1984) stress that temperature trends can only be obtained from flowstones if the calcite is deposited under equilibrium conditions, which occurs only in deep caves where temperature and moisture fluctuations do not take place. The formation of tufa and travertine, in contrast, is a disequilibrium reaction stimulated to a large part by CO₂ degassing resulting from the emergence of groundwater (Michaelis et al. 1985). Despite this prevalent notion, promising results have been obtained from oxygen isotope studies of tufas and travertines in calcareous terrains (Padzur et al. 1988), and it is possible that a paleotemperature curve could be obtained from similar deposits on Fort Bliss.

A final potential avenue of paleoenvironmental investigation concerns examination of biotic material incorporated into tufas and travertines. In addition to providing material for dating, biotic remains trapped in the sediments as they accrete can provide a picture of the surrounding vegetative community (see Section 6.2.2).

6.2.11 Historical Records

Historical records can provide evidence of environmental conditions and changes during the period of recorded history. These records can include, but are not limited to, formal weather

records, vegetation records, photographs, engineering records, diaries, and newspaper accounts of weather events and their effects. One form of this information that has proven very informative in southern New Mexico and western Texas are historic surveyor's records containing descriptions of extant vegetation at the time of survey (cf. York and Dick-Peddie 1969; Buffington and Herbel 1965).

6.3 SUMMARY AND CRITIQUE OF EXTANT PALEOENVIRONMENTAL EVIDENCE IN THE FORT BLISS REGION

This brief summary provides a more critical overview of the state of paleoclimatic knowledge in the Fort Bliss region than was provided in Section 2.8. It includes a review of simulated climate dynamics and an overview of data available from various proxy sources. The best extant global circulation models applicable to the late Quaternary are probably those produced by the COHMAP research group (COHMAP Members 1988; Kutzbach et al. 1993), which are the principal basis for the discussion of atmospheric dynamics in the following discussion. The treatment of empirical evidence highlights aspects of the record that are ambiguous or conflicting, and is followed by discussions of the limitations of two specific types of data that have been used most extensively for paleoenvironmental reconstruction in the Fort Bliss area.

6.3.1 Summary of Late Quaternary Paleoenvironmental Information

According to both models and empirical data, the late full glacial period, which peaked approximately 18 ka, was a time of moist, cool pluvial climatic conditions in the southwest. Simulation models suggest that both winter and summer temperatures were slightly cooler than present, with summer temperatures exhibiting slightly more deviation from modern conditions. The presence of the Laurentide ice sheet resulted in much more extreme temperature gradients through the middle continent, but temperatures during both seasons were relatively moderate in the

southwest, and the annual surface temperature anomaly was only -1.8°C . Precipitation was slightly higher on an annual basis due to considerably higher winter precipitation ($+1.2$ mm/day), even though summer precipitation was lower (-0.64 mm/day). This increase in winter precipitation is due in large part to a strong southward diversion of the jet stream and of attendant storm tracks, to roughly 30°N (a 20° diversion from its typical modern winter location), by strong anticyclonic flow over the Laurentide ice sheet. Although the amount of annual precipitation predicted by the model is only moderate (roughly 10 cm/yr), Thompson et al. (1993) point out that the COHMAP models use a very simplified topographic model that probably underestimates orographically induced precipitation.

Empirical evidence from the full glacial period is largely in agreement with the simulation model. Vegetation records are suggestive of cool, moist conditions. Piñon-juniper-oak woodland appears to have been ubiquitous, with cooler species like Douglas fir common at intermediate altitudes (Van Devender 1990). Faunal records are also indicative of cool, moist conditions (Harris 1989; Elias and Van Devender 1992), and lake levels were high (Markgraf et al. 1984). Although this was the period of maximum alpine glaciation, no evidence of mountain glacier accumulation or periglacial processes exists in the vicinity of Fort Bliss, and it is unlikely that sustained winter freezes were common, although occasional hard freezes almost certainly occurred.

By latest glacial time (approximately 12 ka), the ice sheet was waning rapidly and the jet stream was positioned at approximately 38° in winter. The models suggest that winters were still slightly cooler than present, while summer insolation was higher and temperatures may have been slightly warmer. Winter precipitation was considerably higher than at present (by approximately 2.3 mm/day), but summer precipitation may have been slightly lower than at present. Overall precipitation on an annual basis appears to have been as much as 40 cm/yr greater than present in the general southwestern region.

Vegetation evidence from latest glacial time indicates that the character of regional vegetation had changed little since the full glacial, although an increased incidence of cold-intolerant plants suggests that the frequency and severity of hard freezes was lessening (Van Devender 1990). However, despite the persistence of piñon-oak-juniper woodland, lake levels in the region were apparently falling from 18 ka to 12 ka (Markgraf et al. 1984), which is inconsistent with increasing precipitation predicted by the model. However, the model does predict that temperatures should have been increasing across the southwest from 18 ka to 12 ka, particularly in summer, which may be responsible for the falling lake levels through enhanced evapotranspiration. In contrast to the gradual temperature rise indicated by these data, insect fossils suggest that warmer and drier conditions developed relatively quickly around 12 ka, although vegetative response to this trend continued until about 10 ka. At present, it is unclear whether climate changed dramatically at 12 ka, or the insect and vegetative changes represent threshold responses to more gradual climatic amelioration during the latest Pleistocene. However, the development of the calcic soil on the Isaack's Ranch fill (Gile et al. 1981; Monger 1993a) suggests that the climate was dominantly semiarid throughout the latest Pleistocene.

By early Holocene time (approximately 9 ka), the ice sheets had largely retreated, and global models suggest that circulation patterns were rapidly approaching modern conditions. The winter jet stream was at about 45°N latitude, and upper level winds in the southwest were much diminished from the glacial period. As a result, the models suggest that winter storm tracks were shifted to the north of the Fort Bliss region, and amounts of winter precipitation received had fallen to approximately modern conditions or below, while midsummer precipitation was considerably more plentiful (approximately $+1.3$ mm/day) due to strong onshore flow of moist Pacific air. Daily insolation in summer was as much as 8% greater and in winter as much as 8% less than modern conditions due to orbital forcing; as a result, winter

temperatures were cooler and summer temperatures were warmer than at present.

Empirical evidence suggests that while the principal warm-intolerant species (e.g., Douglas fir, Rocky Mountain juniper) had departed by 9 ka, piñon-oak-juniper woodland persisted in the mountains and the modern desert scrub species were not yet present (Van Devender 1990). Isotopic evidence from the bolson floor and marginal fans (Monger et al. 1993; Monger 1993d) suggests that grasslands probably predominated. Insect faunas represents a continuation of the admixture of mesic and arid-adapted species that developed rapidly around 12 ka. Thus, the empirical evidence indicates transition from late glacial to postglacial conditions, with climate still relatively more moist and cool than present but considerably changed from three millennia earlier.

At approximately 8 ka, continued warming and drying appears to have resulted in a sudden environmental shift in much of the area. No major shift in circulation patterns is indicated by climate models, suggesting that this change was probably a result of various systemic thresholds exceeded as the climate dried. Although many lines of evidence indicate a fundamental environmental shift sometime around 8 to 7 ka, interpretation of the character of that shift varies considerably. Monger and his colleagues (Monger et al. 1993) identified a sudden, -4‰ to -6‰ shift in isotopic carbon from soil carbonates on the fan piedmont at approximately 8 ka. They interpret this negative shift in carbon isotopes as indicating a change from grassland to desert scrub. Unfortunately, this shift is not mirrored in sequences obtained from the bolson floor by Rightmire (1967) and Monger (1993d) (see Section 6.3.2). Other supporting evidence also exists, including a pollen sequence from the Gardner Springs locality on the western side of the Organ Mountains indicating that typical Chihuahuan desert scrub was established during the middle Holocene (Freeman 1972). Van Devender (1990) also identifies a shift in vegetation at approximately 8 ka on the basis of macrobotanicals from packrat middens; however, he states that this shift is indicative of a change from oak-juniper

woodland to a desert grassland with some of the more resilient scrub species interdigitating with grasses across the landscape rather than the rise of Chihuahuan desert scrub. Van Devender (1990) interprets the shift as indicating slightly higher summer rainfall and more frequent winter freezes than at present. Other lines of evidence do not reflect the 8 ka shift; insect faunas continue to exhibit a mix of mesic and xeric species (Elias and Van Devender 1992), open woodland continues to exist in west-central New Mexico, and lake levels continue to fall steadily (Markgraf et al. 1984).

Slightly later (around 7 ka), alluvial and eolian activity increased in the bolson, eroding the Isaack's Ranch unit and initiating deposition of the first phase of the Organ units. Gile et al. (1981) and Monger (1993a) interpret the onset of this activity to increasing aridity in the region, but there is little corroborating evidence for such a shift at this time. However, it is possible that the onset of renewed geomorphic activity at around 7 ka was a lag response to the vegetative changes apparent a millennium earlier that was delayed until vegetation density decreased enough to cross a critical threshold.

By 6 ka, the models suggest that the jet stream had essentially returned to its interglacial station at 50° N latitude. However, greater summer insolation than currently present resulted in stronger onshore monsoonal flow from the Pacific, enhancing annual precipitation compared to modern conditions; temperature during both summer and winter was slightly higher than at present. Since 6 ka, insolation and precipitation have decreased, and they are approaching modern levels as the climate shifted toward increasingly arid conditions.

The enhanced monsoonal flow predicted for the late middle Holocene may have been sufficient to maintain desert grassland until around 4 ka, which Van Devender (1990) identifies as the time of the shift to essentially modern, Chihuahuan Desert vegetation. However, Freeman (1972) describes a more complex model, with scrub vegetation established in the early middle Holocene and changing back to mixed scrub and grassland,

which it remained until it was disturbed during Euroamerican settlement. In west-central New Mexico, the last remnants of the pluvial lakes disappeared by 5 ka (Markgraf et al. 1984), while in the Tularosa Basin, pluvial Lake Otero had shrunk to a small, hypersaline remnant of its former self (Lake Lucero) by the late middle Holocene, and the White Sands dunefield was well-established from erosion of evaporites on the lake pan (Weber and Kottowski 1959).

Notably, with the exception of the shift from scrub to grassland at Gardner Spring (Freeman 1972), none of the local data sets strongly support the notion of an anomalously warm, dry interval during the middle Holocene. This interval, termed the Altithermal Period by Antevs (1948; 1955), has become an entrenched feature in the archeological literature and is invoked regularly in explanatory frameworks of Archaic cultural patterns. Indeed, the interval is arguably present in records from many localities in the Southwest and on the southern Plains, while sediments of the proper age are lacking--presumably itself a consequence of warm, arid conditions--from many more areas (Hall 1985; Bull 1991). However, many others question whether the Altithermal period is a valid model (Mehring 1977; Thompson et al. 1993), arguing that climatic changes are driven by shifting circulation patterns, and thus are apt to be time transgressive and more complex than a simple contrast between "moist, cool" conditions and "warm, dry" conditions. Although the issue is far from settled, the data is presently too equivocal to allow uncritical application of the altithermal model to the Fort Bliss region.

Vegetation evidence suggests that essentially all modern plant taxa (except the few imports that arrived from Europe, such as Russian thistle) were established in the region by approximately 3,000 years ago (albeit probably in different distributions and frequencies), and the mixed insect assemblage gave way to exclusively xeric species by approximately 2500 BP. Stratigraphic evidence suggests that two depositional hiatuses/incisional events of unknown duration occurred around 2100 and 1100 BP. It is unclear at present what the

magnitude and driving mechanisms of these interludes were, but it is safe to assume that they represent some type of environmental shift. Also, although the vegetation record suggests the dominance of desert scrub throughout the late Holocene, the almost total lack of stratification in the bolson sand sheets suggests that they may have accreted under grassy cover. Historical information also suggests that grasscover was widespread in the central basin in the late nineteenth century (e.g., Buffington and Herbel 1965); it also suggests that limited pollen information from the Rotura soil (which is the soil buried by the coppice dunes, and thus represents the pre-Anglo settlement surface) is strongly suggestive of a well-developed grassy cover (Gile 1966a; Hall 1990b).

Mauldin (1995) presents a fairly detailed model of climate change over the last two millennia based on tree ring variations from several localities in the Sacramento and Organ mountains: longer, more distant sequences from west-central New Mexico; an alluvial sequence from Black Mesa, northeastern Arizona; and several regional pollen and macrobotanical sequences. He interprets these diverse data as indicating that an oscillating climatic regime was established by approximately 3000 BP, with relatively cool, moist periods occurring between roughly 3000 to 2000 BP, 1550 to 1250 BP, 950 to 650 BP, and 400 to 50 BP and warm, dry periods occurring in the remaining intervals. Although Mauldin's model is interesting, the use of data as diverse as alluvial records from northern Arizona and tree ring records from western New Mexico suggest that the reconstruction should be viewed with caution; in fact, Hall (1990c) argues that the alluvial records of Black Mesa and Chaco Canyon (which are much closer to each other than they are to the Fort Bliss region) are not comparable, implying that the correspondence between Black Mesa and the Fort Bliss region should be even less so.

6.3.2 Cautionary Critique of Extant Data

As is apparent in the preceding summary, much of the available information on the character of Late

Quaternary paleoclimates in the Fort Bliss region is based on faunal and floral material recovered from packrat middens and on isotopic evidence from soil carbonates. This discussion focuses on the character of this information to highlight the strengths and limitations of that data.

Although packrat midden studies have proven critical to paleoenvironmental reconstruction in the Southwest up to this point, they do have a number of limitations. The principal drawbacks to packrat midden studies are: (1) they are not able to characterize the relative abundance of plants in the area, but rather only give an indication of presence of particular taxa within a few hundred meters of their location (or less, as most packrat foraging tends to occur within about 30 m of the nest); (2) they represent data filtered by the collection habits of an individual organism that lived in a distinct locality, and thus probably do not represent all the contemporary available plant taxa; (3) for the same reason, they may reflect a bias toward anomalously mesic local environments; and (4) they all come from similar local environments and thus do not provide a good picture of vegetation in a full cross-section of the environment. As a result, packrat midden reconstructions do not always agree with other reconstructions from the same region based on other data (e.g., pollen, geomorphic criteria) (cf. Betancourt et al. 1983 and Hall 1983).

Van Devender (1990) presents summary descriptions from packrat and porcupine middens from caves and rockshelters in the vicinity of Fort Bliss; specifically the Hueco Mountains (42 middens from 1270 to 1495 m amsl), Bishop's Cap (12 middens from 1400 to 1465 m amsl), the Sacramento Mountains (13 middens from 1555 to 1690 m amsl). All of these localities are situated on mountain slopes on the flanks of the bolson, suggesting that the flat bolson floor is probably poorly represented, if at all. The impact of the similar location of most packrat middens is compounded by observation of packrat behavior, which suggests that the rodents move laterally away from their dens to scavenge, and generally do not range significantly up or downslope (Elias

and Van Devender 1992). In one respect, this is a valuable aspect of the data because it implies that most packrat midden nests will not represent plants gathered from different ecozones, and thus allows for better resolution of diachronic trends. On the other hand, because all midden sites are situated on the mountain slopes, it implies that they only provide direct evidence of a subset of ecozones within the area of interest, and it is likely that different relief and edaphic factors resulted in strongly different vegetation assemblages elsewhere in the vicinity of Fort Bliss. Further, packrats are likely to seek out the lushest areas, particularly during arid intervals, and thus may leave a record that underestimates the impact of increased aridity on the broader landscape.

Evidence from the bolson is limited and consists primarily of isotopic evidence from soil carbonates (Monger 1993d; Monger et al. 1993; Rightmire 1967). Although several of these data sets exhibit interesting trends, the differences between the different data sets are significant and troubling. Figures 32 and 33 present comparative plots of carbon and oxygen isotope trends from radiocarbon-dated carbonates on the fans and bolson floor. Note that the trends from the fan piedmont (Monger et al. 1993) are approximate because the original publication did not include the necessary numerical data, and the information was therefore transcribed from plots published therein.

Carbon isotopes from the three studies show little similarity. The clearest trend by far is present in the data from the fan piedmont, which exhibits an abrupt shift from $\delta^{13}\text{C}$ values of approximately 1 to 2‰ during the late Pleistocene and Pleistocene/Holocene transition to values in the 7 to 9‰ range after about 8 ka. Monger et al. (1993) interpret this shift as indicating a change from dominantly C-4 grassland to C-3 desert scrub at around 8 ka, which seems reasonable except that (1) C-4 grasses are tropical taxa (Boutton et al. 1980) and would probably not be expected to dominate a Late Pleistocene assemblage formed under cool, moist conditions; and (2) the other two sequences from the bolson do not show the same trend.

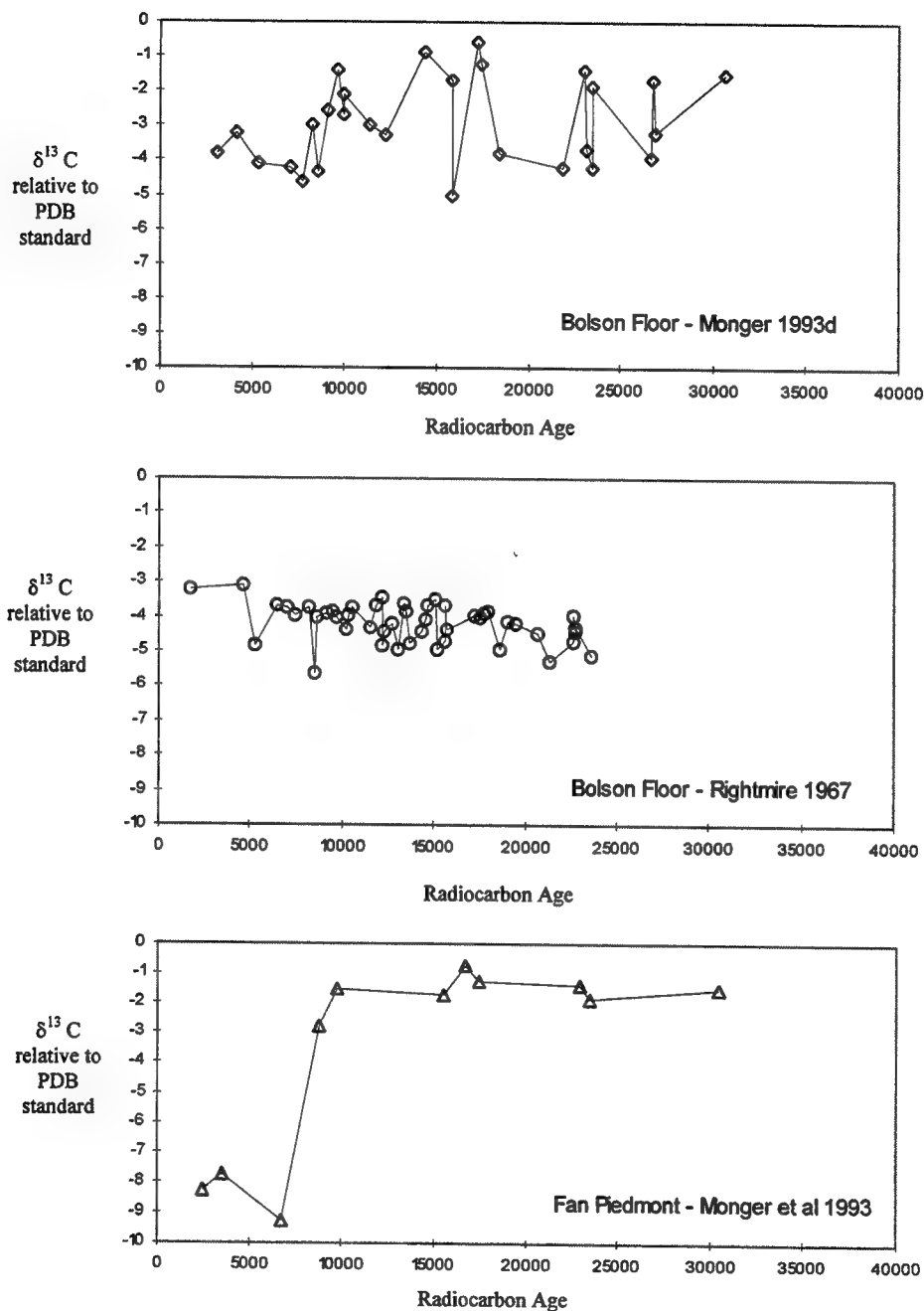


Figure 32 Carbon Isotope Trends from Studies of Soil Carbonate in the Fort Bliss Region.

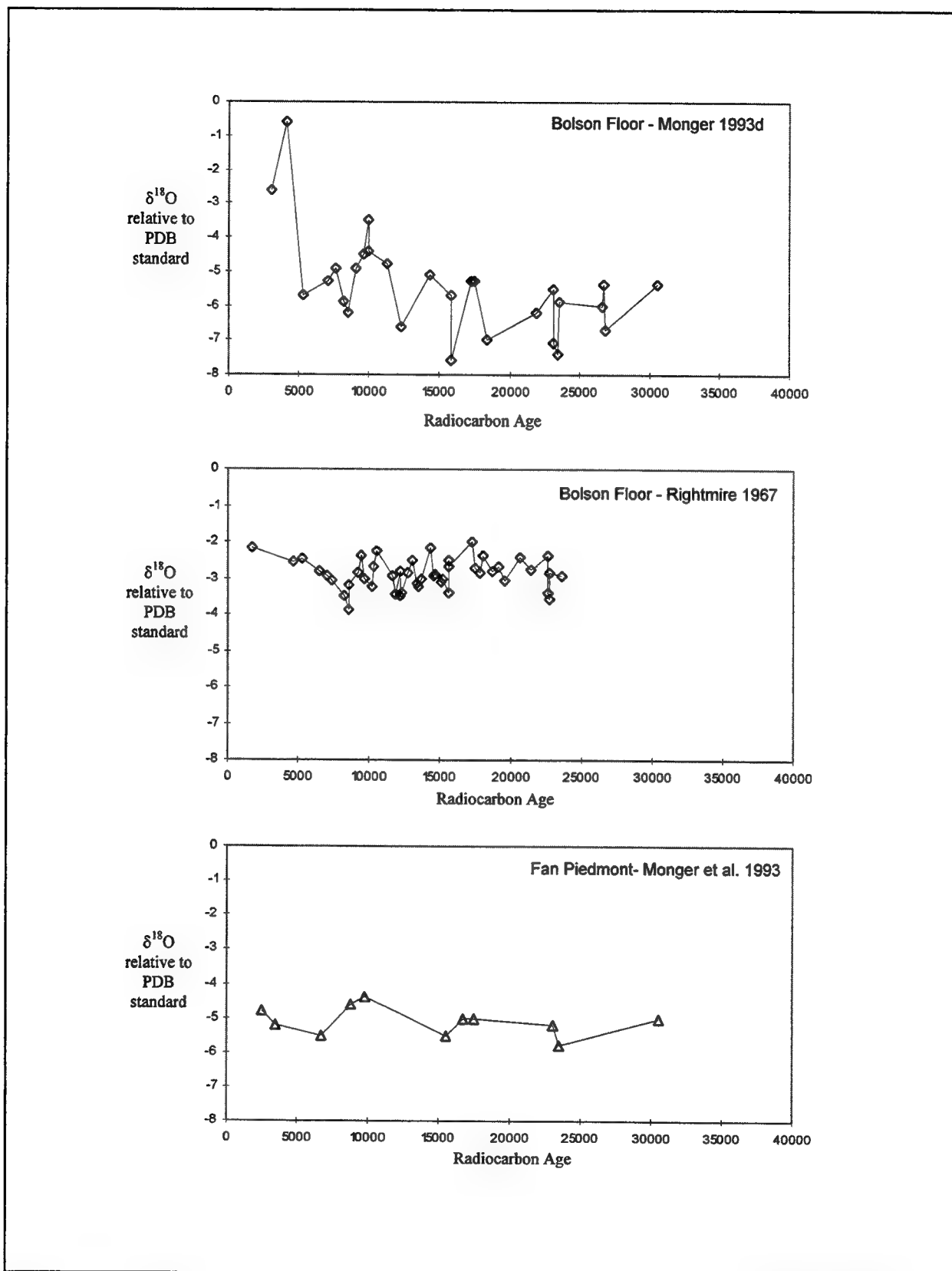


Figure 33 Oxygen Isotope Trends from Studies of Soil Carbonate in the Fort Bliss Region.

Carbon isotopes described by Monger (1993d) from the bolson floor on Fort Bliss exhibit strong variation between those heavier than -1‰ and lighter than -5‰, which nominally represent fluctuations between less than 40% to more than 80% C-4 biomass during the late Pleistocene. Monger recognizes that this variability is problematic and hypothesizes that variable rates of calcareous dust influx may have biased the record. He does note that the Holocene samples seem to stabilize somewhat in the lighter range (roughly 3 to 5‰), and argues that it probably reflects the same phenomenon so apparent in the fan-piedmont samples. The record determined by Rightmire (1967), in contrast, provides a much more internally consistent record with $\delta^{13}\text{C}$ values between approximately 3 to 6‰ that shows a clear, slow trend toward isotopically heavier values through the Late Pleistocene and Holocene. If there is any shift at all in the Holocene in Rightmire's data, it is opposite of the trend apparent in Monger's data (Monger 1993d; Monger et al. 1993), implying increasing C-3 importance.

The oxygen isotope records presented in the three studies are also very different from each other. The fan-piedmont (Monger et al. 1993) exhibits a record of variation between approximately -4 and -6‰ with no apparent long-term trend. The oxygen isotope record from the bolson floor presented by Monger (1993d) is as chaotic as the carbon isotope record from the same source, suggesting that caution should be exercised interpreting its significance. It spans nearly 8‰, but does contain a strong shift in the late Holocene that may be temperature related. Once again, the record presented by Rightmire (1967) is much more internally consistent than the Monger record, ranging between -2 and -4‰. Nominally, these values are indicative of very high mean annual temperatures ($>20^\circ\text{C}$) (Hays and Grossman 1991), suggesting that the content of ^{18}O was probably enriched about 2‰ through evaporation from the soil. Although the Pleistocene part of the record is oscillatory and exhibits no evidence of substantially cooler temperatures during the full glacial, the Holocene part of the curve exhibits a strong, consistent trend of increasingly heavy

values that may strongly reflect warming temperatures through the postglacial period.

In summary, the paleoecologic record is only partially understood in the vicinity of Fort Bliss. While some interesting trends are apparent, there is scant and occasionally contradictory information about the character of paleoenvironmental history in the region. The late Holocene record, in particular, is poorly understood. While broad regional climatic reconstructions are conceptually valuable and probably do have some validity, the mechanism's driving climate change are complex and should be expected to result in changes that are typically time-transgressive and occasionally unique to specific areas. It follows that the key to understanding the Fort Bliss region is continued, directed research designed to answer questions pertaining specifically to the area.

6.4 PALEOENVIRONMENTAL RESEARCH QUESTIONS

Although many additional questions could potentially be posed about the paleoenvironment of Fort Bliss, the following questions provide a good basic overview of the most salient avenues of potential investigation.

- 6-1 What are the paleoclimatic implications of the eolian sequence? The fan sequence? The slope deposits? Soil development?

Data needs: Soil development data derived from a large number of site-specific studies are needed. Comprehensive, refined models of regional stratigraphy are needed.

To a considerable extent, many of these questions can be addressed with extant data. However, there is considerable room for refinement of the basic sequences and for improvement of interpretive linkages. The best opportunity for understanding these problems lies in continual refinement of the questions asked as evidence from a variety of sources mounts. Slope systems, in particular, are poorly understood in the vicinity of Fort Bliss and

can provide a record that differs both in the character of the information and the level of detail from that accessible through eolian and alluvial records.

6-2 What is the nature of sediments preserved in playas? Are any organisms of paleoenvironmental significance (e.g., pollen, diatoms, ostracodes) preserved in playa sediments? What rates of sedimentation are indicated? Can stratified dessication strata indicative of punctuated playa activity be isolated and dated? What are the paleoclimatic implications of the sedimentary and biotic record in playas on Fort Bliss?

6-3 Can significant, synchronous changes in playa size be documented on Fort Bliss? What are the implications for the paleoenvironment? For evolution of the feeder drainage net on the fans?

Data needs: Detailed, chronologically constrained studies are needed of a variety of playa lakes within the post. These studies should include provisions for exposure, sampling, and laboratory analysis of playa sediments, coupled with sampling for chronological control.

Preservation of biotic and sedimentological evidence in playa pans on Fort Bliss is unproven but poses one of the best unexplored opportunities to make quantum advances in knowledge about paleoclimatic and paleohydrologic conditions in the Fort Bliss region. Investigation should focus on a variety of playas, because the degree of preservation of suitable sediments is likely to be highly spotty. Evaluation of size fluctuations through time is also no easy task given the relatively small scale of the playas, but should be possible given provision for extensive chronometric sampling.

6-4 What is the history of lake levels in Lake Lucero, in adjacent White Sands Missile Range? What implications does this have for effective moisture through the

late Quaternary? What is the nature of the biotic and sedimentary record in the lakebed? What is implied about water chemistry, and particularly salinity, at various periods?

Data needs: Sampling and analyses are needed of bottom sediments and former strandlines in Lake Lucero.

Although Lake Lucero is situated outside of the boundary of Fort Bliss, it represents the only extant, quasipermanent water body in the bolson, its potential to address paleoenvironmental questions is unprecedented. It is likely that Lake Lucero and its pluvial ancestor, Lake Otero, were never a good source of water due to very high concentrations of soluble salts. However, if diatom or ostracod records can reveal trends in salinity since the full glacial, they may indicate times when fresh-water input was enhanced or restricted.

6-5 What climatic indicators are indicated by landsnail species? What is the character of oxygen isotopes in snails? Carbon isotopes?

Data needs: Snail taxa with good abundance in the record, and uniform, time-sensitive racemization characteristics are needed.

As discussed above (see Section 4.2.3), amino acid racemization has the potential to provide a valuable tool to interpret site chronology and integrity once an initial investment is made to construct a local curve. Snails also have strong potential to yield localized paleoenvironmental data because of their frequently narrow-niche preferences, and can theoretically provide broader temperature and vegetative data through isotope analysis. This broad range of relevant data potential renders investigation of land snails one of the most important potential avenues of investigation that could be pursued at Fort Bliss.

6-6 How can the stable isotope signatures associated with pedogenic carbonates be

refined, and what are the climatic implications?

Data needs: Radiocarbon dates and $\delta^{13}\text{C}$ values are needed from carefully selected samples of pedogenic carbonate, particularly samples representing earlier stages of carbonate development.

As illustrated previously (see Sections 6.3 and 5.5), carbon isotope analysis of pedogenic carbonates has strong potential to reveal trends in the relative frequency of C-3 and C-4 vegetation, and has already yielded some interesting results on the post (Monger et al. 1993; Monger 1993d). However, the movement of carbon in the soil system is very complex, and repeated dissolution and reprecipitation of pedogenic carbonates can result in the admixture of contemporary and fossil carbon that may seriously complicate interpretation. Therefore, we advocate concentration on early-stage soil carbonates (e.g., filaments and small nodules) where the problems introduced by repeated dissolution and reprecipitation are less pronounced.

6-7 How can archeology refine the faunal record of the region? What are the implications for the paleoenvironment?

6-8 What do the carbon, nitrogen, and oxygen isotope signatures of faunal and human remains imply about the paleoenvironment?

Data needs: Faunal and human remains are needed from archeological contexts.

Many aspects of environmental faunal analysis are not viable in archeological contexts because of the intense series of taphonomic filters imposed by human selection, procurement, and processing strategies. Nevertheless, at minimum, faunal remains in an archeological site can establish the presence of specific taxa in the broader environment at that time. Examination of the environmental preferences typical of each identified taxa can then be used to interpret broad

constraints on the character of the environment at the time of site formation, as well as providing information on the types of ecozones that were exploited. Isotopic studies on bone from archeological sites also have implications for diet, and by implication, regional character of the biotic system, particularly in regards to C-3/C-4 and leguminous/nonleguminous plant ratios. Physical and isotopic analysis of human bone, while complicated by legal and ethical considerations, can also provide considerable data about population health status and diet.

6-9 Are travertines and tufas present around springs or in any of the caves and rockshelters in the mountains? What does the sequence of formation imply about climate? What is the character of incorporated biotic remains (e.g., pollen). What is the character of the isotopic record?

Data needs: Spring, rockshelter, or cave sites are needed with tufa or travertine deposits.

Although many cave sites have been reported in the Hueco, Sacramento, and Organ mountains and on the flanks of Otero Mesa, little detailed geomorphic study of the features appears to have occurred, and it is unclear how common Holocene tufas and travertines may be in the region. However, if late Quaternary tufas and flowstones are present, they have strong potential to address a number of aspects of paleoenvironmental character in the region.

6-10 What is the character of oxygen isotopes preserved in tree rings?

Data needs: Wood samples containing rings are needed, either from archeological or natural contexts.

Oxygen isotopes are indicative of paleotemperatures, albeit in a complex manner that requires careful interpretation. Tree rings are relatively unique records in that successive rings represent fixation by a single organism over a

relatively long span of time, and can therefore minimize the impact metabolic biases have, particularly if the data is used to derive trends rather than absolute temperature estimates. Further, comparison of oxygen isotope values between low and high-growth-season wood can potentially allow one to isolate seasonal influences and better interpret oxygen isotope records from other sources, particularly regarding whether those trends are attributable to absolute changes in temperature, rainfall seasonality, or moisture source areas.

- 6-11 What do carbon isotopes associated with occluded carbon in phytoliths indicate about the metabolic pathways of taxa associated with individual, unidentified phytolith morphologies? What do they indicate about community composition when considered in aggregate?

Data needs: Phytoliths from primary depositional contexts are needed.

The extraction of occluded carbon from phytoliths has been demonstrated to be a viable method for obtaining material amenable to AMS radiocarbon dating and isotopic determination (see Kelley et al. 1991); however, it is hardly a routine procedure and would require close collaboration with scientists interested in developing the method. However, the possibility exists to address a whole new suite of information, in this case, one that is likely to be more commonly preserved in the region than practically any other single source.

- 6-12 What kinds of species are represented in the preserved wood charcoal in features?

Data needs: Wood and charcoal fragments are needed from archeological contexts.

This question is interesting not only from a purely paleoecological perspective (what species were available for use as fuel?) but also from a behavioral perspective, as it may provide an indication of the extent that firewood was ported in to campsites, particularly in the central bolson.

7.0 TECHNOLOGY RESEARCH DOMAIN

Christopher R. Lintz

This chapter investigates the role of technology as a research domain with specific reference to the Fort Bliss region. Technology is defined as the knowledge, skills, methods, and procedures for fabricating and using tools to convert elements of the natural environment into culturally useful materials. Technology covers a tremendously broad array of specific studies which can range from the examination of specific artifacts, to fundamental studies of the full assemblage and feature range upon which inferences about prehistoric adaptations are based. The present chapter examines as background discussions the range of concepts used to examine technology/technologies, summarizes the theoretical models, surveys the literature of the Fort Bliss region to identify gaps in a number of technological issues, and postulates a series of viable research questions related to technology.

7.1 BACKGROUND DISCUSSIONS

Although technology is seemingly a straight forward research domain principally dealing with material culture remains, archeologists have used the term technology in a multitude of ways. It includes the support assemblages, organization and culturally patterned behaviors underlying (1) the methods of raw materials acquisition, (2) the sequence or stages in manufacturing implements and features, (3) the use, damage, and repair of implements and features, (4) the patterns of discard, or storage and recycling of implements, and features. Since all materials, organizations, and behaviors potentially change through time, technology forms the basis for describing cultural variations upon which inferences about past adaptations are derived.

In a few instances, technology has also been erroneously used as a term synonymous with assemblage, as in discussions about the array of tools stashed on site as "a curated technology." Technology generally studies material culture items

(artifacts and features) to derive information about prehistoric procedures, ideas, strategies, and the organizations of groups underlying specific task and activities; whereas assemblages generally refer to the specific collections of implements and features used by the group. Due to the breadth in the scope of technology (ranging from culturally transmitted ideas to specific objects), some aspects of technology overlap other research domains of settlement patterns, subsistence practices, cultural interactions and, of course, chronology.

Recently, Ellis (1994:81-99) has developed the concept of technology as a means of investigating prehistoric cultural adaptations. Assuming that cultural systems of shared behaviors and traits are transmitted by socialization from one individual to another, then the adaptation of cultural systems involves both a "reproduction mode" to replicate behaviors perceived to be effective in meeting the group's goals and an "adaptive mode" which attempts to adjust behaviors to perceived changing environmental conditions. Ellis advocates that:

An adaptation is a knowledge base and a decision making structure socially transmitted within, and historically implemented by a community of people in order to meet their subsistence and other goals in an environment that contain a finite array of materials that can serve as the resources people use to meet their goals (1994:83).

Drawing on the notions developed by Winner (1977), Ellis notes the basic structure of technology consists of three parts: 1) organization involving the social arrangement of people, 2) apparatus referring to the raw materials, tools and features, and 3) techniques the culturally transmitted procedural knowledge about how an individual/group accomplishes a goal, and background knowledge, involving perceptions about the natural and cultural environmental setting within which people operate.

Since people are rarely devoid of an existing material assemblage, Ellis points out that a group's ultimate survival goals (primarily subsistence and shelter needs) are accomplished by several tiers or levels in the structure of basic technology. A distinction is made between "use technology" (the apparatus, organization, and techniques employed to achieve an ultimate procurement, or processing resource goal - usually related to subsistence), and "support technologies" (the apparatus, organization, and techniques employed to create the tools and features contributing to or comprising the apparatus of the use technologies). Several layers of support technologies underlie a specific kind of use technology. In addition, several kinds of use technologies are linked together to acquire and convert natural resources into a consumable product. For example, first order support technologies (organization, techniques, and apparatus) exist for the procurement of raw materials (i.e., knappable resources). Secondary order support technologies (organization, techniques, and apparatus) convert raw materials into projectile points, just as other second order support technologies make the dart shafts and atlatls. Third order support technologies combine these various components into a projectile delivery system. This projectile delivery system constitutes the apparatus portion, (along with hunting group organization, stalking/killing techniques, and the knowledge of animal behavior) of a "hunting use technology" for the slaying of game. Other use technologies (each with several subordinate levels of support technologies) exist for a butchering use technology, a processing/cooking use technology, perhaps an animal production storage use technology, and an animal product consumption use technology. Complementary systems exist for a range of plant resources, as well as for the goals of providing clothing and shelter.

The technological notions advanced by Ellis are important since they explicitly outline a way of looking at how materials are assembled to achieve a specific end, and understanding the relationship between support technologies and use technologies within a functional context. It forces archeologists to contemplate the problems and procedures which

must be addressed to meet a group's survival goal, and to consider the interrelationship between tools made of different kinds of raw materials as a functional part of the assemblage. This perspective is quite contrary to the procedures implemented in most archeological reports, which organize the materials descriptions around the raw materials types (chipped stone, groundstone, ceramic, organic, etc.), but make little effort to discuss the interrelationships through the delineation of activity areas and relationships of implements of different material types. Progress in understanding how specific prehistoric groups are organized and behave is apt to be slow until archeologists deal with issues beyond mere descriptions organized by raw material types.

A second aspect of Ellis' technological approach involves comparing the recovered archeological assemblage at a site against the expected assemblage derived from the various tiers of support and use technologies to make inferences about the site's function and role in a settlement system. Rarely were all support or even use activities performed at a single site, and the absence of expected materials in an assemblage may be almost as informative as what components are present. This approach has the potential to define complementary sites and the spatial and behavioral range of activities across the landscape along the procurement-processing-consumption continuum. Site assemblage data in conjunction with knowledge about paleoenvironmental conditions, models of resource distributions, seasonal resource availability and chronometric data all allow archeologists to formulate inferences about how people organized themselves at various times in the past. Testable hypotheses can then be developed for examination at other sites. Clearly preservation, sampling limitations, and contextual associations must be critically evaluated in defining the position of a site in the settlement system.

The final aspect of Ellis' approach establishes a set of interrelated testable hypotheses which, when answered in a stepwise manner, provides information about a group's organization and adaptive strategies. The interrelated hypotheses are

hierarchically arranged to examine (1) site functions, (2) the spatial organization of individual technologies, (3) stability and change in technology and subsistence, (4) delineation of the arrays of technologies and subsistence resource bases for a temporally specific interval, and (5) delineation of adaptive strategies for a specific time interval by delineating the array of site functions, seasonality (scheduling), and degree of subsistence orientations along the forager-collector continuum.

The strength of Ellis' approach involves an explicit way of using the basic structure of support and use technologies to infer adaptations from the artifact assemblages present at a series of relatively contemporaneous sites across different land forms and throughout a region. It provides a theoretical mechanism for archeologists to use in comparing and interpreting patterns in relative contemporaneous site assemblages, and for searching for contrasting patterns in assemblages dating to other periods.

The approach is holistic and elegant, but not without practical problems in its implementation. As a heuristic device, it assumes that sufficiently intact sites will be located on all landforms to permit the identification and reconstruction of complementary activities. In practice, this may be a major problem at Fort Bliss. Some parts of the technological approach may be easily implemented, especially where contextual relationships are relatively intact. Application of other parts of the technological approach (where landforms are not conducive to the preservation of segregated occupational contexts) may require diligent study and a modicum of luck to understand the nature of prehistoric activities. Many regions have dynamic landforms experiencing differential periods of stability or kinds and rates of deposition, and erosion. Landform settings will differentially affect the preservation of complementary behavioral activities.

In practice, sites with neither temporally diagnostic artifacts nor datable samples are especially difficult to analyze with respect to technology issues, regardless of landform. Many sites consisting of

little more than sparse fire-cracked rock or lithic debris scatters may have to be regarded as ubiquitous low level cultural "background noise" in the suite of activities. In other situations, the consistent correlation of specific tool or feature types to specific landforms suggests fundamentally different, but temporally vague activity patterns. Initially the distribution may only be useful in delineating gross activity differences. However, if the tool or feature type is sufficiently morphologically distinctive to permit confident and replicable identification, it may eventually be found in datable contexts, which will permit classification of such behaviors to a specific time period. Thus, the program involves long term studies and not quick or easy solutions.

Another drawback in implementing this technological approach involves the procedures to recognize, and ascribe significance to cultural variability as a means of measuring adaptation. In lieu of recovering potentially highly perishable materials, and/or understanding the contextual relationships of artifacts, the criteria for distinguishing genuine behavioral differences are vague, difficult to quantify, and somewhat capricious. How does an individual interpret assemblage variability and ascribe behavioral differences? Clearly, the tactic involves the investigation and analysis of numerous components in order to understand differences in the site functions, seasonal variations, and organizational differences.

7.2 THEORETICAL MODELS AND EXPLANATORY APPROACHES

A somewhat more pragmatic approach of dealing with technology recognizes the inherent complexity of the subject and structures this complexity in a manner that highlights the relationships of the technological components. By explicitly identifying these relationships new questions can be formulated which yield additional information underlying human behavior. The complexity of technology involves the integration of:

- (1) raw materials (to fabricate artifacts and features);
- (2) cultural materials (general artifacts, features, rock art, etc.);
- (3) a spatial scale (ranging from a single item through feature clusters, activity areas, sites, environmental or landforms, to regional investigations);
- (4) a temporal/ateporeal component (preferably attributable to a stage or phase level); and
- (5) analytical modes including morphology, material production, function/use/damage, and recycle/curation/disposal).

The relationships of these components can be conceived as a five dimensional matrix table with a primary goal of providing an analytical framework for structuring technological questions. Ideally the intersecting matrices delineate a succinct, and isolatable research question. However, the structure of the matrix also characterizes the relationships between variables.

Due to the conceptual unwieldiness of a five dimensional matrix table, some technological components can be conceptually linked together to produce a three dimensional matrix table, more amenable for consideration and discussion. The three primary axes consist of a raw material-cultural material-spatial scale axis, a temporal/ateporeal framework axis, and an analytical orientation axis (Figure 34). The recombination of the material-spatial and analytical orientation axes create some problems, and these will be discussed below.

7.2.1 The Material Types and Spatial Dimension

The material-spatial axis of the matrix actually involves the melding of three relatively distinct technological components. Material types consists of both raw material resources and cultural

materials. Both of these categories correspond to Ellis' apparatus component in technological studies (Ellis 1994). The spatial scale component acknowledges that valid technological studies can occur on various micro to macro levels and yield important technological data relevant to understanding technological behaviors. In general, as the analytical scale of space increases (feature based associations, buried activity areas, sites, landscape and environmental zones and regional studies), the level of confidence in establishing associations with a single group are apt to become lower. Nevertheless, macro scale studies yield important insights into prehistoric utilization of landscape diversities.

The listing of raw material resources should be regarded as illustrative, but includes raw materials for producing both tool components and features. Floral resources include plant food stuff (pollen, fruits, nuts, seeds, leaves, stalks, and roots, etc.), and materials for manufacturing implements or feature products (fibers, wood, leaves, etc.). Faunal resources similarly include the raw foodstuff (organs, meat, marrow, digestive track contents, etc.), and products needed for implements (hides, sinew, organs, feathers, bones, horns/antlers, shell, etc.). Sediments/clay resources include raw materials potentially useful in manufacturing ceramics (clays and tempers), adobe/mortars, pigments, and other materials where earthen materials are acquired, modified and transported to a state where they can be archeologically detected as being manipulated by people. The lithic resources include the broad suite of materials that include quarry blanks, cobbles, and pebbles suitable for modification by knapping, pecking/grinding, and heating.

The realm of cultural material types is distinct from raw materials, since it applies to the manufactured tangible aspect of culture - the object (artifact or feature) - and not the process or knowledge of production. Note that materials in these categories are generic types which do not necessarily stipulate any specific form, method of manufacture, stage of completion, or specific function. These items may represent artifacts

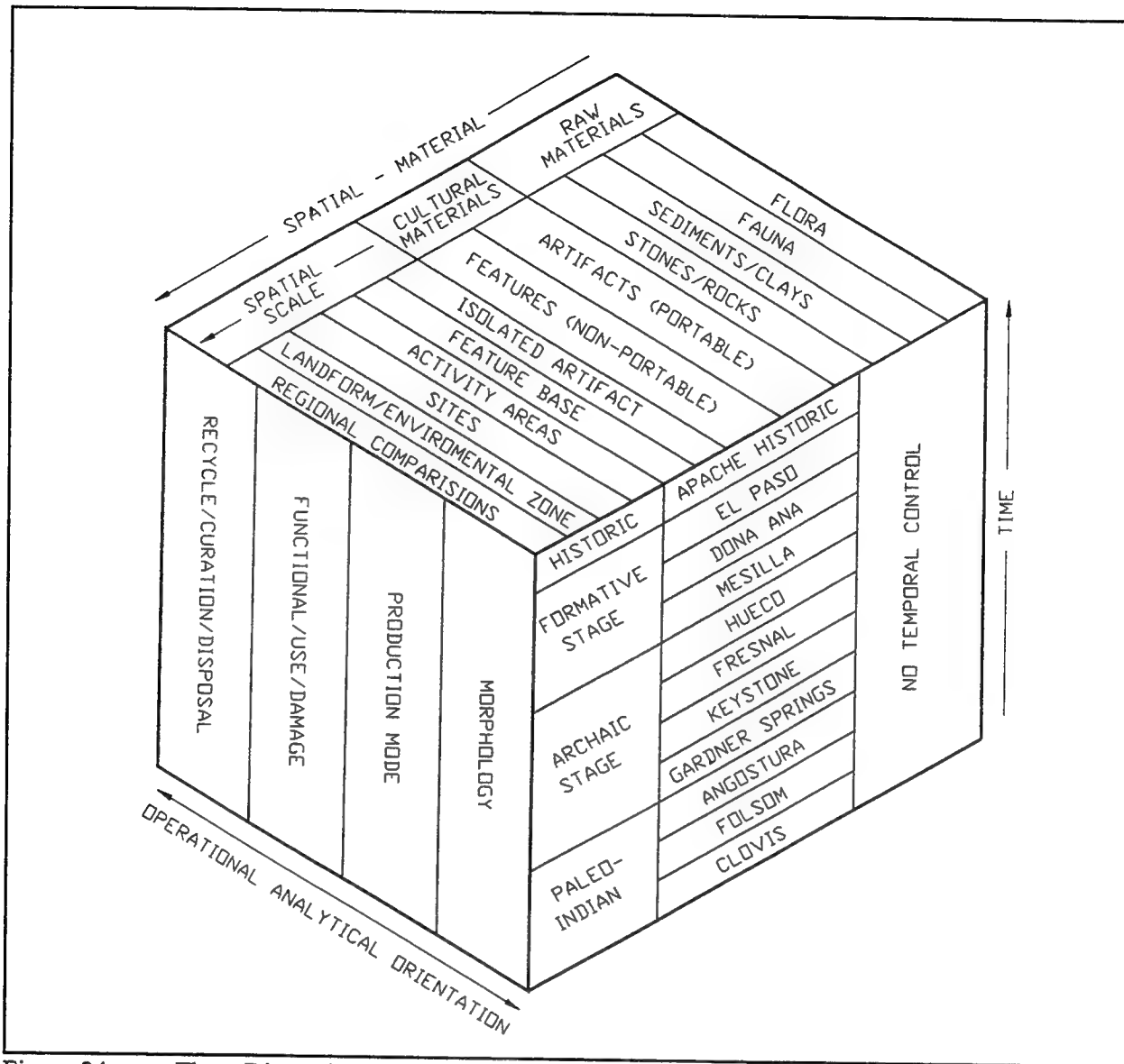


Figure 34 Three Dimensional Matrix of Technological Components.

made from a single kind of raw material (e.g., baskets), or they may represent composite materials (e.g., a house). The intent of recognizing this realm as a discrete entity along this axis is to permit the kinds of analytically oriented studies that can focus on specific kinds of artifacts or features. The intent is not to identify the full range of artifact types or feature types, for that is one of the analytical orientation topics. Rather, the inclusion of artifacts and features recognizes the importance of technological studies of single classes of cultural materials from a temporal,

spatial or analytical perspective.

The spatial scale segment acknowledges that legitimate technological studies can focus on differential levels of space ranging from the location of an isolated artifact or feature, up through distributional studies the size of a region or culture area. Although the provenience of an isolate may be recorded with relative precision, its association with other artifacts and features may be contextually unknown. Feature based associations (materials within structures, pits, hearths, ovens,

etc.) are apt to have relatively good associational contexts. The association of materials within activity areas surrounding features become more tenuous and may require geomorphic interpretation of the locality dynamics before the association of artifacts can be properly defined. Even though the three dimensional spatial proximity between artifacts is no assurance of contextual relationship due to potential intervening depositional events, it is equally true that with increasing physical distance, the scale of interpretative resolution must become coarser (Chang 1958). On many parts of Fort Bliss, landscape dynamics are sufficiently active to preclude the confident construction of artifact assemblages ascribable to a specific component even on small site areas. Despite these limitations, important technological studies can be accomplished on the environmental or landscape and regional level by altering the tactic of investigations to macroscale distributional patterns of specific kinds of artifacts and features. Without abundant absolute dates it may be difficult to temporally relate many of these macroscale distributional study findings. However, significant patterns in the occurrence and frequencies of select features and distinctive artifacts provides valuable behavioral information about prehistoric land use practices, and general landscape activities.

7.2.2 The Temporal Dimension

The temporal framework is a major matrix axis, since it provides the ability to control time depth and, where feasible, permits delineation of the succession of technological issues. Three temporal states are recognized: synchronic time control, diachronic time control, and atemporal control or the absence of time control.

For illustrative purposes, the regional stages (following Willey and Phillips 1958) and the cultural sequence of phases as defined by MacNeish (1993) have been added. However, since many of the Archaic phases are based on results from stratified rockshelters where numerous natural and cultural factors translocate artifacts into different contexts, considerable investigations are still needed to verify and refine the technological

context and chronological controls for the Fort Bliss sequence of phases, as well as understand the composition of the artifact assemblages in other environmental settings. The present intent was merely to provide labels for discussing synchronic and diachronic technological changes.

Synchronic studies involve the compilation of data from near contemporaneous time periods. These kinds of studies examine material culture as a "slice of time" and characterize activities and behaviors occurring in diverse settings and resource zones. Chronological control is most reliably assessed through absolute dating, especially in dynamic landscapes prone to episodes of deflation and mixing. Some kinds of artifacts and features (perhaps projectiles, ceramics and contiguous structures) may be assignable to a specific period on the basis of morphology alone. Furthermore, as brief occupation sites with good contextual relationships are identified and studied, other aspects of a material assemblage can be related to specific synchronic studies.

Diachronic studies examine the changes in material culture through time. Such studies can range from the examination of one class of material (projectile points, ceramics or fire-cracked rock hearth feature [Whalen 1994; Leach 1993]), to comparisons of material assemblages from a series of components, and synchronous phase assemblages (MacNeish 1993). Diachronic studies provide the basis for identifying the dynamics of culture, changes in behavior and, when temporally correlated to variations in other natural and cultural environmental factors, provide the primary data for postulating adaptive/maladaptive cultural patterns.

7.2.3 The Analytical Orientation Dimension

The analytical orientation axis of the technological matrix is concerned with identifying manufacture, use, and discard behavioral patterns, which can be examined by material class, spatially or temporally. Analytical orientation is concerned with studies about an artifact/feature's form and its stages of formation, use, and disposal.

One analytical approach to technology is morphology. The first analytical orientation on the matrix is concerned with the study of artifact form and classification. Such studies can range from the mere creation of "pigeon hole" typological classifications of specific artifact forms (as with projectile types), to the characterization of the range of tool forms within an assemblage. In the most rigorous approaches, factor analyses can be used to delineate pertinent attributes, whereas cluster analysis defines group memberships. Other aspects of the assemblage can be used to ascribe significance to the groupings.

Another approach to technological studies is that of production. The second analytical orientation on the matrix is concerned with the manufacturing trajectories of tool production including delineation of the strategies of raw material acquisition, and stages of tool production for all components of an assemblage. Although most often conceived as applying to a single kind of raw material, such as the stages of manufacture of a particular chipped stone tool form, in a larger sense, technological production also pertains to the related implements and features needed to make the target artifacts. The technological approach varies according to the kinds of medium used, and whether the manufacturing process involves subtractive or additive characteristics (e.g., chert knapping reduction vs. clay modelling in ceramic production).

The next category on the analytical orientation face of the matrix is that of function/use/damage. This approach is concerned with how an implement was used, and its relationship to other components of the artifact assemblage. Typical approaches involve studies of gross morphological forms (inferences about use edge angles on tools, wear patterns on ceramics, etc.), detailed microscopic use wear evidence such as abrasions and polish on the edge of chipped stone tools, or analyses of residues on the implements.

The last category is recycle/curation/disposal. This technological study element pertains to the strategies or processes and evidences of use by

recycling, curating, and/or discarding the array of implements used by a group of people at a select point in time, or through time, to modify and manipulate their environment. The use of the term recycle here is taken to mean secondary use of items whose original function changes (Camilli and Ebert 1992:120). The reworking of groundstone as hearth rock or as chipped stone cores are two examples of recycling. Another element of technology is curation. In the technological sense items which are important within a group's technology (food processing equipment), or an important personal implement are likely to be curated or maintained in anticipation of future use. Often these kinds of items are not discarded on sites unless they are broken or worn out (Hitchcock 1982:370). Some of these items may be left on sites in anticipation of future need and/or use (e.g., metates). Binford refers to these sorts of items as site furniture (Binford 1978:339). Disposal or discard is a category which reflects the ultimate trajectory of implements or byproducts of implements into the archeological record. Implements or byproducts of implements are disposed of as they have been deemed unusable as they are worn out, broken beyond repair or simply not worth the effort of curation (Hitchcock 1982:371). Many analyses conducted on chipped and groundstone assemblages for instance are directly applicable to questions of activities and functions. They can also infer occupational stability and perhaps to some extent seasons of use.

7.3 DEFICIENCIES AND NEEDS OF THE EXISTING KNOWLEDGE

Recent work in the El Paso area has highlighted some deficiencies and needs in the regional database. Whalen (1994) set out to investigate the role of residential mobility in late prehistoric (or Formative period) adaptations to the Jornada Mogollon area. In pursuing his investigations at Turquoise Ridge it was noted that few large scale excavations at Formative period sites are represented in the Jornada region as compared to the rest of the Southwest. This may be a fair statement for all periods in the Jornada area. Most of the sites where excavations have been conducted

are situated in only two environmental zones: the central basin and the Rio Grande Valley. More extensive work on sites in other environmental zones are necessary in order to more fully understand the variation within the region.

Site structure is not reported for many of the sites which Whalen used as comparisons for his Turquoise Ridge investigations. The architectural structures themselves have been the object of inquiry and only brief, cursory descriptions of artifact assemblages and features are given. Whalen notes that the chronology is imprecise when it comes to Formative sites and structures. Also, there is a great deal of morphological variability among the known structures and there are few clear chronological or geographic patterns to this variability (Whalen 1994:23-26). There is a need for extensive excavation and intensive analyses at a range of sites selected for their ability to yield data on activity patterns, subsistence practices, group compositions, stability of residence and seasons of occupations.

Miller (1993) focuses on ceramic developments during the Doña Ana phase (Transitional Period: A.D. 1100 to 1200). Miller notes that despite 40 years of archeological work in the Jornada Mogollon, a reliable and consistent ceramic chronology is still lacking. Questionable ceramic associations have been further exacerbated by the fact that much of the work in the region has consisted of surface surveys (see also Hard et al. 1994:267-283). Miller notes that it has been nearly impossible to identify the purported architectural features of this period, either pithouses and/or surface rooms, due to the fact that the majority of Transitional Period occupations have been recorded during large scale surveys.

A continuing problem is a lack of chronometrically dated assemblages which would allow for such developments to be independently tested, as well as a lack of excavation data to examine ceramic associations and their relationships to architectural or midden features (Miller 1993).

Miller goes on to note that the absolute contemporaneity of ceramics and differing architectural forms reported at sites such as Alamogordo Site 3 and the Hatch Site cannot be assumed. The few available reports on excavated sites lack a consistency of ceramic descriptions and provenience information with which to examine potential differences among ceramic types and architectural forms. There as yet has been no verified occurrence of pithouses and surface structures with absolute ceramic continuity (Miller 1993).

Some specific vessel form differences may be temporally significant. Studies of vessel form through time coupled with analyses of decorative styles should produce more precise understanding of Jornada ceramic trends relative to regional cultural developments.

Stone artifacts are common on the region's sites but less intensively studied than ceramics (Whalen 1994:92). Whalen points out that tool function analyses are uncommon in the region's literature and groundstone tool studies are more rare than chipped stone analyses although the number of studies have increased in recent years.

MacNeish (1993:140) notes only occasionally have projectile points been classified into types and adequately described. "Even when typed, the various attributes and terminology have not been defined adequately in this area, in contrast to what has been done in adjacent Texas and northern Mexico, Oklahoma, and California" (MacNeish 1993:140). O'Hara (1988:191-208) notes that little work has been conducted or reported from excavations of sites with the potential of contributing to a basin wide chronological typology for projectile points. Appropriate surrounding regional typologies have been called into use to provide wide ranges of comparisons for locally derived materials.

The development of a regional or subregional projectile point typology would serve as a relative chronological sequence which would help establish a secure chronological framework for the region.

Projectile points used as chronological markers along with a ceramic typology, intrusive ceramics that are dated in other parts of the Southwest and chronometric dates from sites in the area would allow investigators to look at changes in the human record through time with more certainty of their chronological anchor.

Whalen (1994) finds two notable deficiencies in understanding Formative period lithic technology despite the progress of the last decade. He notes that most studies come from small, ephemerally occupied camps. No large studies from Formative sites with long occupation histories have been accomplished. The other notable deficiency is that the lack of chronological control has obliged investigators of extant studies to consider the long Formative period as a single unit. As a result, little is known about intraperiod variability in lithic usage.

Church et al. (1994), working on Fort Bliss, located, documented, and sampled 228 lithic sources during their three year fieldwork effort. They point out that prior to their study lithic source studies in the region were poorly defined material types based on visual criteria and an incomplete understanding of the nature, distribution, and variation of the lithic resources available. These deficiencies have inhibited investigations on mobility, trade, lithic procurement strategies, and intraregional interaction. Their work will enable studies to move forward on those investigative fronts mentioned above. Church et al. (1994) also note the paucity of recognized lithic procurement sites.

7.4 RESEARCH QUESTIONS

Humans have often been defined in terms of our special ability to make tools, and archeologists in the past have seen human progress largely in technological terms. For instance, in the nineteenth century the human past was divided into "ages" of stone, bronze, and iron. The analytical focus on a variety of aspects of technology allows a gain of information regarding what raw materials were used, the source of the raw materials, the

possible place and mode of production, and a possible date or period of manufacture and/or periods of use. Technology touches on every aspect of prehistoric existence, subsistence, settlement, etc. Clearly, inquiries into technology often overlap into other research domains.

The following research questions are framed within the context of the Analytical Orientations as part of the Technology Matrix illustrated in Figure 8.1. Often questions are not and can not be couched within a discrete category such as "Function/Use/Damage" without also touching on, or including other categories such as scales of spatial dimension (e.g., landform, region) or temporal dimension (e.g., Doña Ana phase or Paleoindian). The following questions should be viewed from the flexible perspective of being applicable at all spatial scales of analysis (i.e., regional, zonal [environment], intersite, and intrasite). As has been stated previously the technology matrix has the possibility of a myriad of permutations for questions moving from synchronic to diachronic, from relatively low levels of abstraction to higher levels of abstraction. Questions posed here are but a few. Answers to questions asked evolve into other questions which can be formulated using the matrix. The goal is to move toward higher levels of complexity and abstraction.

7.4.1 Morphology

This category of questions deals with the individual aspects of tools but larger frames of reference are sought. The following questions should be investigated in order to achieve the broader characterization of artifact patterning through time and/or space.

- 7-1 What are the spatial and temporal parameters for projectile point types known to exist in the region?
- 7-2 What are the temporal parameters for specific groundstone forms?

-
- 7-3 Does the morphology of groundstone change between broad environmental zones (i.e., basin floor, distal fan, proximal fan, mountain slope, upland mesa) on Fort Bliss?
 - 7-4 Does the morphology of groundstone change through time within those broad environmental zones?
 - 7-5 What is the pattern of morphological variability of architectural structures through time?
 - 7-6 What is the pattern of morphological variability of architectural structures over all broad environmental zones (i.e., basin floor, distal fan, proximal fan, mountain slope, upland mesa) on Fort Bliss?
 - 7-7 What is the ceramic chronology for the area and the region? What are the spatial and temporal parameters for the types and varieties?
 - 7-8 What ceramic types are associated with the architectural forms in the region?
 - 7-9 What architectural features and ceramic types are associated with the Doña Ana phase (Transitional Period)?
 - 7-10 How does ceramic vessel form relate to function through time?
 - 7-11 Are there specific broad environmental zones (i.e., basin floor, distal fan, proximal fan, mountain slope, upland mesa) that should be targeted for lithic sourcing studies? If so, what bearing does this have on acquisition strategies and can these be discerned?
 - 7-12 Can specific lithic sources identify changes in strategies through time?
 - 7-13 Can sources be targeted for discrete temporal periods?
 - 7-14 Do aggregate and morphological analyses have value for the Fort Bliss area as a whole?
 - 7-15 Are there patterns to be perceived within these two methods that can be perceived through time or on a geographical scale?
 - 7-16 Can groundstone sources highlight mobility patterns within the Fort Bliss region? Is there a difference east to west, north to south?
 - 7-17 Can clay or temper sourcing effectively map acquisition strategies within the Fort Bliss region? Is this achievable?

7.4.3 Function/Use/Damage

This category is concerned with how implements were used, (e.g., microwear and edge damage analysis on lithics or ceramics), and their relationship to other components of artifact assemblages. These can also contain dimensions of time and space to discern patterns within features, sites, etc. The following questions should be investigated in order to achieve the integration of data at a higher level and to delineate adaptive strategies through time.

- 7-18 What are the differences in lithic usage between broad environmental zones (i.e., basin floor, distal fan, proximal fan,

7.4.2 Production Mode

This set of questions involves the manufacturing trajectories of tool production. This involves raw materials acquisition, stages of tool production, and the delineation of temporal and spatial parameters. The following questions should be investigated in order to answer questions of spatial organization of individual technologies, stability and/or change in technologies, and ultimately stability and/or change in adaptive strategies overall.

- mountain slope, upland mesa) on Fort Bliss?
- 7-19 Do patterns of lithic use and edge wear change through time?
- 7-20 What are the patterns of variation in function/use among groundstone tools in the different broad environmental zones (i.e., basin floor, distal fan, proximal fan, mountain slope, upland mesa) on Fort Bliss?
- 7-21 What are the patterns of variation in function/use among groundstone tools through time?
- 7-22 What are the functional differences among ceramic vessel forms at broad environmental zones (i.e., basin floor, distal fan, proximal fan, mountain slope, upland mesa) on Fort Bliss?
- 7-23 What are the functional differences among ceramic vessel forms through time?
- 7-24 Do changes in form/function relate to organizational aspects or social arrangements?
- 7-26 What are the patterns of reuse or recycling of lithic materials at differential scales of analysis (i.e., region, zone, etc.)?
- 7-27 What are the patterns of reuse or recycling of lithic materials over time?
- 7-28 What are the patterns of recycling of ceramic materials over broad environmental zones and/or time?
- 7-29 What are the patterns of size variability for metates over the broad environmental zones and through time?
- 7-30 What patterns of artifact variability can be discerned in regard to caches in the area?
- 7-31 What are the temporal patterns for caches?
- 7-32 What are the spatial patterns in regard to caches?
- 7-33 What sociological implications do caches portray?

7.5 DATA NEEDS

7.4.4 Recycle/Curation/Disposal

The questions posed here deal with the strategies or processes and evidences of use by recycling or reuse, curation or caching, and disposal of implements or features. There are elements of both time and space which can be invoked in this category. Ultimately, answers to these questions prompt questions of a higher order involving social organization, adaptive strategies, and changes through time.

- 7-25 What are the patterns of recycling of manos and metates within or among broad environmental zones (i.e., basin floor, distal fan, proximal fan, mountain slope, upland mesa) on Fort Bliss?

A deficiency in the area's database which is obvious but bears repeating, is that there are relatively few large-scale excavations in the area and on Fort Bliss. While archeological excavations are not themselves a CRM goal of military installations, it is often the case that key information with which to address gaps in the regional data base can only be obtained through excavation methods. This is the case for the region around, and including, Fort Bliss. There is a need for large scale excavations at sites of all periods and within the different environmental zones encompassed by Fort Bliss's boundaries. These large-scale excavations in different settings and temporal periods are more likely to encounter data (in this instance technological data) which will highlight the full range of variation within the area.

These projects can focus on various data needs within Fort Bliss boundaries and for the Jornada region as a whole. Site structure is a data element which needs amplification. The recordation of the patterning of architectural features along with their attendant features such as trash pits, middens, storage facilities, etc., and artifact assemblages are necessary so that they may yield information on the whole range of prehistoric lifeways (i.e., subsistence practices, group composition, stability of residence, and seasons of occupation). The study of the technological aspects of all of these elements aid in bringing the full picture into focus. These projects would lend themselves to acquiring data on the technological/morphological variability among features, structures, and sites and delineate changes through time and over the landscape.

Data needs in both lithic and ceramic developments across geographic and temporal planes can be addressed through large-scale excavation projects as well. Data are needed on the lithic and ceramic associations and their relationships to architectural and midden features.

Additional intraperiod temporal and spatial controls are needed on lithic and ceramic tools. Accumulation of temporal and spatial data for features is needed as well.

Continuing data gathering and analyses on all categories of lithic and ceramic tool functions are needed. Continued data gathering on the morphological, functional, and use-wear patterns of tools is essential. However, spatial analyses are crucial to the analysis of tool production and tool use. Continued acquisition of technological data on lithic and ceramic raw materials (and sources of those raw materials), their acquisition and use over time and space are essential to answering higher level questions of groups' social organization and adaptive strategies. These aspects cannot be inferred from tools alone. These must be inferred from results drawn from spatial distributions of stages of tool production processes relative to the distribution of raw materials. Inferences regarding the social organization of tool use can be derived from spatial distributions of tools within sites, from

site to site, and the distribution of tools relative to exploited resources or paleolandscape features in the absence of direct evidence for exploited resources (Ellis 1994:91).

8.0 SETTLEMENT PATTERNS RESEARCH DOMAIN

Patience Elizabeth Patterson

We consider it a given that the material culture of the past human groups in the El Paso area reveals to us a structured set of relationships. In the analysis of these structured relationships we look at several different levels of data (e.g., intrasite, intersite, and regional data). The sets of data needs for the analysis are basic site information, such as site location, site characteristics, and structure, and artifact variability. The analysis of the articulation of the environment, subsistence, and technology allow us to recognize and explain adaptive strategies, and through these explanatory frameworks ultimately understand how and why cultures change through time. These data allow us to define settlement types and patterns (Struever 1968).

In order to understand the prehistoric cultural systems that existed within the boundaries of Fort Bliss, we have to understand the context in which they thrived. That context is first an environmental one, and what we see archeologically are the remains of cultural adaptations to a highly variable, semiarid environment. To see all those archeological pieces in context, we have to understand how cultural groups interacted with their environment. One way to develop an understanding is to model how they might have lived in and adapted to changes within that environment in order to meet their subsistence needs.

Land-use models allow us to look at how a culture might have used all of the environment and how it was organized in order to live, thrive, and survive. Therefore, the ethnographically and/or ethnohistorically derived groups mentioned herein are groups directly associated with the El Paso area or which have similar environmental contexts the parallels of which can be extrapolated to make empirical generalizations to be incorporated in land-use models.

Taking a systemic approach (Binford 1964, 1965, Clarke 1968, Flannery 1968), we view humans, culture, and nature as integrated segments of a system. Changes in one segment can cause changes in other segments. In our cultural ecological focus in this research design, we keep at the forefront the recognition of the interactions between humans and their environments. A human sociopolitical organization, as part of an interactive system, has a repertoire of strategies for dealing with change. These range from immediate small-scale responses to longer-term pervasive changes in subsistence strategies. Implicit in this interaction is the idea of "adaptive strategy." Kirch (1980:129) broadly defines adaptive strategy as the set of culturally transmitted behaviors -- extractive, exploitative, modifying, manipulative, competitive, mutualistic, and the like -- with which a population interacts or interfaces with its natural and social environment. These patterns of behavioral variation can be linked to environmental characteristics, with implications for the archeological record of settlement and subsistence systems (Jochim 1991:308).

Looking at the archeological universe we wish to explain and/or predict, we must come to understand all facets of the interconnections of the "system." The system, in this instance, is the physical domain, the environment in which present-day Fort Bliss exists. The system is the past environment in which groups of people existed. It consists of the archeological manifestations of those groups who lived on, moved across, and sought to maintain an existence within their chosen physical environment and their own cultural system. The system is not only the present physical environment but the changes in that environment as well that have had a bearing on the archeological manifestations of the past and what we see now and how we interpret what we see. This taphonomic process in this segment of the system will be dealt with subsequently.

Synchronic land-use models are hypothetical formulations of past cultural adaptations that

provide a basis for further archeological investigation. Models presuppose that humans are not a passive part of the environment. The situation is dynamic, and influences move from one segment of the system to the other. Models usually contain descriptions of how prehistoric peoples/cultural systems might have functioned at a given point in time and territory, and perhaps include some predictions as to the archeological implications of those systems. Strategies for acquiring at least the essentials to live and exist within an environment are part of those models. The "essentials" are activities that are repeated over and over, on a daily, seasonal, and yearly basis. These repetitive articulations of the component parts of the cultural system and the environment in which they take place allow us to identify, within the archeological record, causes and effects we wish to study (i.e., cultural changes through time). Although the strategies are repetitive in that water, food, and fuel must always be obtained, changing environmental factors (environmental variability) may require adjustments within the strategies in order to meet subsistence objectives.

Settlement patterns usually refer to the distribution and arrangement of specific sites or activity loci on or over a particular landscape (Kirch 1980:139). There are several different factors that operate in decision making regarding settlement placement. For hunter-gatherers, some of these factors are proximity of economic resources, shelter and protection from the elements, and view for observation of game and strangers (Jochim 1976:47-53). In our own study area, water is certainly a prime factor in settlement placement. Settlement patterns, then, are inextricably linked with the natural environment through subsistence strategies and other culturally manifested decisions.

Humans within different resource procurement strategies utilize their environments in different ways, adjusting to environmental fluctuations through mobility, scheduling, and technology. Two economic systems discussed here are hunter-gatherers and cultivators. Environmentally, we place our group or groups within an arid to

semiarid landscape very much like our present study area.

8.1 CONSTRAINING RESOURCES

In a discussion of land use by a group or groups utilizing an economic system of hunting-gathering, four basic criteria can be pointed out. "The primary function of economic activities is the provision of the necessary sustenance for the population" (Jochim 1976:16). We assume, as do others (e.g., Jochim 1976; Binford 1982; Gould 1980; Yellen and Lee 1976:27-46), that the primary objective of the satisfaction of sustenance also includes materials considered necessary for human viability. These four criteria are (1) water, (2) food, (3) fuel, and (4) shelter; each is necessary for long-term survival of any human group. There may be others to be included, however, herein we focus on these four basic necessities. It may be said, of course, that no matter the time or the place, these are necessities for human survival.

The environment itself -- its ecological setting and climatological factors -- determine where and when the resources, or bases of the necessities, are available. An economic system such as hunting and gathering is critically dependent upon the environment. Hunter-gatherers are an element in an ecosystem. They cannot isolate themselves from their environment. Little or no buffering stands between them and the other components of the system. Their relationship to the land, to its flora and fauna, and to their fellow humans is intimate (Dunn 1968:228). The interdependency of segments of the system, such as climate, elevation, soils, precipitation, and vegetation, create the ecosystem within which human groups survive. All these segments create a dynamic and temporally and spatially fluctuating environment with human groups as a segment of the system modulating their behavior in order to subsist.

8.1.1 Water

Hunter-gatherers must adapt to variables within an environment in order to gain what they need. Their behavioral flexibility and their adaptive

strategy in the face of environmental fluctuation is the buffer between them and their environment. The timing of available resources and their placement within the landscape, to some degree, determine when, where, and for how long groups will place their camps. Water is an absolute necessity. Hunter-gatherer groups, their organization and placement, are determined by the availability of this resource (Gould 1980:53, Jochim 1976:51). In an arid to semiarid environment there may be permanent, semipermanent, and/or ephemeral sources of water. Permanent sources are rivers, streams, and springs. Permanent sources like rivers are usually at lower elevations, such as valley floors. Streams and springs that are considered permanent sources are most likely located at much higher elevations in mountains. Semipermanent sources, such as streams or precipitant runoff from higher elevations to lower alluvial fans, usually occur on a seasonal basis. Ephemeral sources are precipitant runoff into pools or catchment areas, and playas located on the desert floor. Playas are low areas, ephemeral lake basins (see chapter 2), which hold rainwater for indeterminate (usually brief -- days or only weeks) periods. High evaporation rates create short-term supplies of water. Hunter-gatherers then are "tethered" (Taylor 1964) to sources of water for the most part. In arid environments, this may require them to move from one source of water to another, depending upon its variability both spatially and temporally, or the depletion of the resource through evaporation and/or use. The Dobe area !Kung and the ≠Kade pan area /Gwi and //Gana San, located in the Kalahari Desert in South Africa, are ethnographic examples of groups exhibiting this type of adaptational behavior (Lee 1976:74-97; Tanaka 1976:98-119).

8.1.2 Food

Most other living segments of the environmental system are water dependent as well, but the adaptations are such that the placement of plant and animal communities within the environmental milieu is just as highly variable as is water. These resources make up the second basic necessity for

human groups: food. One food source for hunter-gatherers is game. This resource provides both food and other items that might be referred to as manufacturing items, nonfood resources, such as hides, bone, and sinew. Those portions of animals not consumed are utilized in other ways, such as for clothing, shelter, and weapons. Animals, small or large, move across the landscape, acquiring their own resources to survive. Thus, hunter-gatherers must be mobile in order to follow these resources when and where they are available. This necessary mobility pulls against the specifically sited water resources. Seasonal fluctuations of game can imply either presence or absence of the particular species or relative numbers of the species. For example, some species may migrate to another area during a given season, return at another, and some species may remain within the same environment but the population may be diminished during a season. Different species occupy different niches within the environment. For example, deer generally occupy upland, forested areas, while bison occupy grasslands. Temporal and spatial parameters operate for each species within an environment. Thus, there are pulling effects of both game and plant resources due to movement and range, and differential areas of resource availability, respectively. Human groups must then situate themselves temporally and spatially so that they optimize their opportunities for water and food, and minimize the risk involved in environmental variability (Lee 1972:339; Silberbauer 1972:287).

8.1.3 Fuel

Another necessity is fuel, chiefly wood. In an arid environment, wood will be available in particular niches within a given range or territory of hunter-gatherers. Fuel sources, such as trees, may be confined to higher elevations where watered areas sustain their growth, and where temperatures and soil moistures are conducive to growth and viability. Ephemeral water sources are less likely to sustain considerable growth of any but the more xeric species. Fuel sources then would also have tethering effects due to their locality where water is more abundant (Tindale 1972:244). When trees

are not available, other more opportunistic sources of fuel, such as woody plants, and grasses may be gathered in areas where they are found (e.g. Ford 1977:200).

8.1.4 Shelter

Shelter is the fourth and last of the basic necessities for survival discussed here. Shelter for highly mobile hunter-gatherers by necessity is nonpermanent. Their structures tend to have a minimum of constituents (i.e., made of hides or brush) which might be gathered on the spot during construction given the appropriate environmental surroundings. The hides and poles that might make up a structure could be transported, assembled, and disassembled with relative speed and ease. Opportunistic shelter in the form of rockshelters, overhangs, or caves might also be utilized. The Tarahumara, for instance, have a preference for rockshelters (Pennington 1963; Hard and Merrill 1992).

The following two sections summarize key aspects of the natural environment from the perspective of identifying and explaining prehistoric settlement patterns. Although these sections parallel to some extent the discussions we have previously presented in Chapters 2.0 and 4.0, here we expand upon those discussions and develop an environmental context for alternative models of adaptive use of the landscape.

8.2 GEOMORPHIC VARIABLES AND ALTERNATIVE LAND-USE PATTERNS

Physiographically, Fort Bliss, situated north and northeast of the city of El Paso in extreme west Texas and south-central New Mexico, is considered part of the Basin and Range Province. The Fort Bliss maneuver areas are situated entirely in the Mexican Highlands section (Bolson subsection) of the Basin and Range, while McGregor Guided Missile Range extends northeast into the Sacramento section of the Basin and Range. Principal landforms on and near Fort Bliss include the Tularosa Basin and Hueco Bolson, which represent two continuous graben valleys, and a

variety of block-faulted mountain ranges and highlands flanking the valley floors. Principal ranges flanking the basins include the Franklin, Juarez, Organ, and San Andres Mountains on the western side of the Tularosa/Hueco valley, and the Hueco Mountains, Sacramento Mountains, and Otero Mesa on the eastern side of the valley. Another series of graben valleys, including the Jornada del Muerto and Mesilla (or La Mesa) Bolson, is present west of the Franklin/Organ/San Andres Mountain chain. Here, the Rio Grande River has entrenched up to 100 m into the bolson floors, forming the Mesilla Valley. At present, the Rio Grande is incised from 200 to 500 ft (60 to 150 m) below the bolson floor. The portion of Fort Bliss in the Hueco Bolson occupies the unentrenched northern part of the basin, and has no through-flowing trunk stream.

The Tularosa and Hueco Basins form a continuous valley that is oriented primarily north-south in the more northerly Tularosa Basin and turns northwest-southeast in the Hueco Basin. Notable intrusives include the Jarilla Mountains in the southern Tularosa Basin and the rocks of Hueco Tanks State Park in the northeast Hueco Bolson. The basins are dominated by broad, gently sloping alluvial fans and fan-piedmonts that spread out from the surrounding mountains and flat, dune-mantled basin floors broken by numerous small extant and relict playas. The mountains on the flanks of the valleys are characterized by steep, rugged slopes mantled by variable amounts of scree and colluvium. Otero Mesa consists of a gently sloping, undulating surface mantled with variable amounts of fine surficial sediment. Elevations above mean sea level on Fort Bliss range from approximately 1,200 m (3,900 ft) in the cantonment area, which is situated on and just above the uppermost terraces of the Rio Grande River, to approximately 2,650 m (8,825 ft) in the Organ Mountains.

It is worth noting again that studies of packrat middens (Van Devender and Spaulding 1979; Van Devender and Riskind 1979; Betancourt et al. 1990) from the area suggest there has been no substantial environmental change since 8000 BP,

when modern conditions developed. These modern environmental patterns can be utilized as a baseline for investigations regarding the majority of the prehistoric past and its developments through time. Recent work (Mauldin 1995) indicates there were fluctuations or oscillations occurring, perhaps regionally, which had a bearing on settlement and subsistence.

The modern climate of Fort Bliss varies from semiarid in the highest areas of the post (e.g., the Sacramento Mountains) to arid in the Tularosa and Hueco Basins. The region is characterized by long, hot summers and relatively short, mild to moderately cold winters. Temperature typically exhibits large diurnal and annual variability. Temperatures in the mountains are slightly cooler in winter due to the elevation difference.

Average annual precipitation is low and occurs primarily in the form of thunderstorms from late summer through early autumn. Average annual precipitation in El Paso, Texas, is under 8 inches (195 mm), while in Alamogordo, New Mexico, north of Fort Bliss it is approximately 10 inches (254 mm). Over 65% of precipitation in El Paso and 66% in Alamogordo occurs as brief, heavy thunderstorms in June through October. Most of this precipitation falls so rapidly that it cannot effectively infiltrate, and brief, high-energy runoff is commonly associated with these storms. In the highest mountains, annual precipitation is approximately 12 to 18 inches, and proportionally more of the precipitation occurs as snow in winter. Annual snowfall is on the order of 3 to 5 inches in the basin and 12 to 25 inches at high elevations. Measurable snowfall occurs in the basin occasionally, but rarely exceeds 1 to 2 inches or lasts on the ground more than 24 hours. Potential evapotranspiration is roughly 10 to 12 times annual precipitation, and is enhanced by light but sustained winds that prevail during most of the year.

In Chapter 2.0, Abbott notes that three of the 11 recognized soil orders are mapped on the post. These soil orders are Aridisols, Entisols, and Mollisols, and they reflect the influence of the arid

climate to varying degrees. For a complete discussion of the soils, see Section 2.3.

Another component of the environment that has an obvious bearing on human adaptation to the area is the vegetation. The vegetation of the Fort Bliss area is inextricably linked with the other components (i.e., physiography, climate, and soils). According to Satterwhite and Ehlen (1980), edaphic factors are the major influences on the distribution of plant species.

The vegetation in the study area, although placed in the northern Chihuahuan Desert by Shreve, is thought by other plant geographers to be disturbance or disclimax communities, having developed from the true climax vegetation; Desert Grassland. The replacement of the climax grass communities by shrub-dominated communities has occurred over the past 100 years or more as a consequence of grazing practices (Satterwhite and Ehlen 1980:11).

In general, the vegetation is dominantly low shrubs, especially mesquite-broom snakeweed that grow on the coppice sand dunes on the basin floor. The playas often have mesquite-broom, snakeweed-soaptree yucca or broom-snakeweed-sand sage vegetational types. The alluvial fans and mountain slopes have creosote-tarbrush and creosote-range ratany vegetation types with sotol and lechuguilla evident as well. The mountain slope vegetation consists of desert shrubs and small trees as well. Plant communities in the higher elevations in the mountains (such as the Sacramentos) consist of pine, juniper, and oak trees (O'Laughlin and Crawford 1977:191-198, Kenmotsu and Pigott 1977).

Again, prior to incorporating the geomorphic variables with the various land-use patterns, we must define and describe those landforms. Monger (1993) has delineated six major landforms on Fort Bliss: (1) La Mesa Basin floor occupies the Hueco Bolson, is of early to middle Pleistocene age, and is the most extensive geomorphic surface on the

post as well as the oldest; (2) Fan-Piedmont is the sediment apron surrounding the mountains in the study area and is composed of alluvial fans, interfan valleys, and coalescent fans, or bajadas; (3) Youngest Basin Fill are younger deposits occupying depressions within the La Mesa Basin floor and are associated with the Petts Tank and Lake Tank geomorphic surfaces; (4) Bedrock Landform occurs in the upper Organ, Jarilla, Franklin and Hueco Mountain areas not covered with Quaternary sediments, and is composed of various igneous and sedimentary rocks with minor amounts of metamorphic rocks; (5) Dunes Landform composed of the areas of deep sand covered with enough deep eolian sediments (several meters deep) to merit delineation as a separate landform (although most of the study area, especially the basin floor, is covered with coppice dunes and eolian sheet deposits, the areas of deep sand and sparse interdune areas were designated *Dunes*); and (6) Fault-Complex Landform composed of fault scarps, associated linear basins, and downthrown blocks (soils associated with the fault complex vary in age, thickness, and pedogenic development). Eroded soils, which are often buried by historical eolian sediments, are common on the scarps. Sequences of buried soils are common in the trough-shaped basins (Monger 1993a:3-19). It is worth noting that Monger states that much of Fort Bliss has been deflated to various degrees and reburied numerous times (Monger 1993a:35).

Hard and Mauldin (1986) define five major environmental zones for the region for their land-use modeling purposes: (1) the Riverine zone is the Rio Grande drainage, floodplain, and adjacent areas for which Monger has no corresponding landform as the area studied did not include off-post sites; (2) the Mountain zones are the bedrock uplands corresponding to Monger's Bedrock Landform; (3) the Mountain Periphery zones are bands about 5 miles wide, adjacent to the mountain zones that include alluvial deposits and also encompass several larger playas corresponding to Monger's Fan-Piedmont landform; (4) the Central Basin zone is the expanse of desert between the east and west mountain peripheries, and is a

generally homogeneous plain consisting largely of mesquite coppice dunes including Monger's La Mesa Basin floor, Dunes, and Fault-Complex landforms; and (5) the Basin-Playa zones, defined as areas enclosed by a one-mile radius around smaller playas that dot the basin corresponding to Monger's Youngest Basin Fill landform.

Each geomorphic variable or landform on Fort Bliss has its unique environment. Given this environmental variability, we assume that hunter-gatherers and cultivators in their economic pursuits would have utilized these landforms differently. In order to understand the archeological contexts of the present, we hypothesize regarding the past usages of those environmental components given subsistence needs, technological capabilities, and the strategies used to minimize risk in a highly variable arid environment. Water is the most pivotal of all the resources, especially in an arid environment. As such, adaptive strategies that complement the wet and dry seasonal periods and take advantage of the florescence of plant foods in their own environmental niches seem most appropriate for the subsistence and maintenance of human groups. Efficient use of resources is achieved through placement of habitation areas (base camps) or short-term hunting/collecting camps where there is a congruence of resources. When that congruence is either nonexistent or variable, scheduling and logistical approaches to subsistence are necessary.

Within the Fort Bliss boundaries, the Mountain zone landform comprises those areas in the Organ, Franklin, Hueco and Sacramento mountains. This landform contains the only areas that are forested. Juniper (*Juniperus monosperma*), piñon pine (*Pinus edulis*), and oak (*Quercus undulata*) are the major species occurring in the higher elevations of the Sacramentos and Organ mountains with extensive lands of ponderosa pine in fillmore canyon. Elm, hackberry, mesquite, cottonwood, and willow all occur in lower and well-watered elevations and in isolated draws. Shrub communities that occur along with these species at lower elevations are agave, shaggy mountain mahogany, rabbitbrush, beargrass (*Nolina*), and

broom snakeweed (Satterwhite and Ehlen 1980; Kenmotsu and Pigott 1977). Sources of water in mountainous regions would most likely be streams and/or springs. Meat from deer and other small fauna whose habitat includes mountainous areas would be available. Other necessary elements, such as animal skins, and antlers would be derived from the faunal resources. Firewood would be available for fuel in this environmental zone. The resources available to hunter-gatherers and cultivators consist of water, and food in the form of plants, nuts, berries, seeds, meat, and fuel. Both economic systems made use of all the environmental zones. It is a matter of proportional usage and scheduling. These mountainous environments would most likely be utilized during those seasons when food resources would be available (e.g., during the late summer and fall): piñon nuts and juniper berries would be collected in the higher elevations where those trees occur.

The Mountain zone would have water available throughout the year in the form of streams or spring and perhaps catchment areas which hold snow melt, etc. Resources available during the winter would be species such as deer and rabbit. Plant foods are unlikely to be available during the winter, especially in this highest zone. It is unlikely that base camps would be situated in this zone during the winter due to the scarcity of these resources. Fuel and water would be present year-round. Shelter in this zone would be the most critical during the winter months. Unless caves or deep rockshelters were available for habitation, with a water source nearby, it is likely that foraging parties would move through this zone during the dry winter months. This may be true for both hunter-gatherers and cultivators practicing a mixed subsistence strategy. Hunter-gatherers are likely to reside in camps at lower elevations in mountain peripheries or on or near the Rio Grande. Farmers would be more likely to reside at camp sites located in an intermediate zone, such as the alluvial fans zone or near the river. Cultivators would subsist partially on stored foods and utilize the mountain zones in a logistical way (i.e., specific hunting parties) to pursue deer and/or rabbit or collect larger-sized firewood.

The Mountain Periphery zones are bands about five miles wide, adjacent to the mountain zones that include alluvial deposits and also encompass several larger playas. This corresponds to Monger's Fan-Piedmont landform. The Mountain Periphery zone is most likely the zone that has the most, if not constant, use. Its placement between the mountain and the central basin zones makes it optimally situated for the exploitation of all three zones, although Anderson (1993:54) contends that this zone contains no sites dating to MacNeish's first two phases of the Archaic (6000 through 2500 B.C.) (cf. Carmichael 1986a:147-148).

Plant resources are those such as mesquite (*Prosopis juliflora*), grasses, fourwing saltbush (*Atriplex canescens*), whitethorn acacia (*Acacia constricta*), datil (*Yucca* spp.), small-leaf sumac (*Rhus microphylla*), prickly pear (*Opuntia* spp.), *Agave* spp., Mormon tea (*Ephedra* spp.), sotol (*Dasylirion wheeleri*), and other cacti. These plants would be available from March through October in varying schedules of florescence. Grasses would be available for the longest period of time (i.e., April through October); others would have their greatest abundance from May through August (Anderson 1993; Kenmotsu and Pigot 1977; O'Laughlin and Crawford 1977; O'Laughlin 1978; Satterwhite and Ehlen 1980; Wetterstrom 1978). Animal species available as resources would be jackrabbit (*Lepus californicus*), and cottontail (*Sylvilagus auduboni*). These animals would be available in this zone throughout most of the year. Their own productivity is much in concert with the availability of water (rainfall) and plant resources. Mule deer (*Odocoileus hemionus*) and pronghorn (*Antilocarpa americana*) would be most available in the fall and winter seasons in the higher elevations in the alluvial fans zone (Anderson 1993; Hard 1982; Mauldin 1993b; Mauldin, Leach, and Amick, 1995; Whalen 1977; Whalen 1978). Hunter-gatherers would have likely employed a foraging strategy in this zone, while cultivators would have utilized the area in a residential and collecting or logistical strategy. This zone was utilized in later periods (i.e., the Mesilla and El Paso phases), by cultivators as sites for planting crops in spring, harvesting in the fall,

and as an area where residential camps were located year round. The larger playas located in this zone receive greater amounts of water in the form of runoff from the higher elevations. These are likely to be the site of crop planting and cultivation (Carmichael 1986a; Hard 1982; Mauldin 1986).

The Central Basin is the expanse of desert between the east and west mountain peripheries and is a generally homogenous plain consisting largely of mesquite coppice dunes. This zone includes Monger's La Mesa Basin Floor, Dunes, and Fault Complex landforms. Water is by far the most problematical resource in the basin. There are no permanent sources of it in the basin at all. The wet season is from May to September. What water there is collects in the small playas that dot the basin. Depending upon amounts collected, temperatures, and evapotranspiration, standing water may last only a few days to a few weeks. Today, the most prevalent plant community in the basin consists of mesquite (*Prosopis glandulosa*), broom snakeweed (*Xanthocephalum sorothrae*), fourwing saltbush (*Atriplex canescens*), soaptree yucca (*Yucca elata*) and dropseed grasses (*Sporobolus* spp., *Muhlenbergia porteri*, and *Hilaria mutica*) (Satterwhite and Ehlen 1980). Studies show that prior to the late 1800s, there was significantly less mesquite in this zone (Kenmotsu and Pigott 1977). Annuals appear seasonally in the basin and were an important economic resource (Carmichael 1986a). Plant resources would be most abundant from April through July. Mesquite pods remain on the shrubs into the fall and are a most important resource (Basehart 1973; Opler 1983). Fuel available in this zone would be some smaller shrubs, such as mesquite. Animals available for hunting would be cottontail and jackrabbit, at their peak in the summer (Hard 1982:20). The greatest coincidence of resources, especially in this zone, is the summer. Hunter-gatherers could perhaps utilize a foraging strategy in the basin (Binford 1980) and camp where there are congruences of water and other resources. Cultivators would most likely utilize a logistical strategy whereby they send out gathering or hunting parties for specific resources in this zone.

Their base camps would probably be located closer to their planted fields (Hard and Mauldin 1986:21).

The Central Basin Playas include the numerous small playas which are scattered across the basin floor (see Figure 2) as well as several large playas, such as Old Coe Lake, which abut the Alluvial Fans. This zone corresponds to Monger's Youngest Basin Fill landform. The soils in the playas tend to have a higher clay content than the surrounding sandy soils in the basin. As such, these soils have a high moisture-retention factor, and this characteristic is an important factor in growth and distribution of plant species (Satterwhite and Ehlen 1980:36). Plants that are typically found in these playas (when not inundated) are grass, creosote, and saltbush (Carmichael 1986a:49-50). Fuel, in the form of shrub-sized plants (mesquite), would be available in this zone to some extent. Again, studies have indicated that prior to the late 1800s there was less mesquite in this zone (Kenmotsu and Pigott 1977). During wet periods (i.e., July through September-October), intensive but spatially variable rainfall occurs throughout the basin. The playas may fill with water but climatic conditions aiding evapotranspiration may dissipate these resources quickly. Cottontails and jackrabbits should be plentiful to hunt at their peak during the summer, and they may also be present in other seasons. The playa areas within the basin will clearly affect the placement of campsites. Hunter-gatherers in a foraging strategy may utilize a playa and surrounding resources until they are depleted, then move on to the next available playa where water is evident. Cultivators are more likely to use a collecting strategy and target specific resources in these areas. Late summer and fall would be the time of greatest resource congruence in these areas (Hard and Mauldin 1986).

In a semiarid environment, such as the study area, there is high variability both temporally and spatially. Temporal variability refers to yearly changes in the types and amounts of resources. Spatial variability refers to changes in the location or types of location in which resources occur. Overall environmental variability is directly related

to behavioral variability (Gorman 1972; Jochim 1976, 1991; Yellen 1977). In these instances hunter-gatherer populations exhibit high mobility profiles. The exigencies of infrequent and scattered rainfall require (in some cases perhaps) almost impromptu spatial or locational adjustments in order to meet subsistence needs. Water is the basic core of our integrated system. It is the dominant limiting factor. The productivity of a desert region is almost a linear function of rainfall (Odum 1975:188). Water in this environment tends to have a "tethering" effect (Taylor 1964) upon a given population. The populations in the study area are tethered to the playas in the bolson or water sources in the mountains, Rio Grande, or at the base of alluvial fans where runoff may have accumulated. However, spatial incongruities in the availability of other resources requires a "pulling" against the tether by utilization of different mobility strategies to the benefit of the population (Binford 1980).

8.3 ETHNOGRAPHIC AND ETHNOHISTORIC ANALOGIES

Many known hunter-gatherer groups are/were located in semiarid regions (Gould 1980; Lee 1972, 1979, 1984; Silberbauer 1972, 1981; Tanaka 1980; Tindale 1972; Yellen 1977, 1978) and generalizations about hunter-gatherers have been offered (Bettinger 1977; Jochim 1976; Yellen 1977, 1978; Binford 1980). The use of ethnographic analogy and ethnohistorical sources from similar environments and past populations in the immediate area can be valuable tools as well (Yellen 1976:47-72). While social, demographic, and geographical factors are different between some of our past cultures and the examples set out here, the environmental adaptations or the adaptational strategies may be very similar and therefore valuable in providing testable hypotheses. Binford, in his "Methodological Considerations of the Archeological Use of Ethnographic Data," states, "model building and testing can be related to ethnographic facts but verification of propositions would remain a problem to be solved by the formulation of hypothesis testable by archaeological data" (1968:270).

The G/wi San of the Central Kalahari, a nonhierarchical society living in an arid region of Africa, live off the unimproved resources of their arid environment by hunting and gathering. They are entirely dependent upon uncultivated, untended plants and wandering wild animals (Silberbauer 1981:191). The G/wi's location is predisposed to those areas where plants, animals, and water are necessarily sufficient and within the bounds of their territory. All these resources may vary over space and time. Therefore, the G/wi exploitation range is by necessity fairly large (4,000 km²) (Tanaka 1980:79), the groups or bands are relatively small and fluctuate given resource availability, and there is high mobility (Silberbauer 1981:191). Plant foods are the mainstay of the diet, and with the exception of good tsama melon seasons (when they are gathered every other day), plant foods are gathered every day and consumed at the morning and evening meals following collection (Silberbauer 1981:202). They are also the main source of fluids in all but the 6 to 8 weeks of the year during which rainwater can be found in pools (Silberbauer 1981:198). The foraging range for these daily activities is approximately 5 km. When closer areas have been depleted of edible plants and the round trip exceeds 10 km or so, the G/wi move with all their belongings to a fresh area where food plants are abundant (Tanaka 1980:66).

Other hunter-gatherer groups such as the Dobe !Kung San also live in the Kalahari. They reside in an area to the northwest of the G/wi San. Their territory is only about 2500 km², almost half of that of the G/wi. However, the G/wi have no permanent source of water as do the Dobe !Kung. The Dobe are "tethered" around eight water holes surrounded by a belt of waterless, uninhabited country (Lee 1972:331). The camp is the basic residential unit and the focus of subsistence activities. Membership at each water hole is very dynamic and changes constantly. During the dry season, the water holes are the centers of activity. As food supplies are exhausted in the immediate area, the Dobe move farther from the water hole and carry water with them. When that runs out, they rely on fluid-bearing plants. The G/wi are

more dependent on these fluid-bearing plants than the Dobe.

The G/wi San and !Kung San (or Dobe) have high residential mobility, low-bulk inputs, and regular, daily food-procurement strategies. Binford (1980:9) places the G/wi and the !Kung San in his category of "foragers," and notes that this type of system or strategy may be reflected in a variability of the contents of residential sites and result in a fairly low archeological visibility.

Groups that have shifted from a purely foraging strategy to a more agriculturally based subsistence should reflect logistical strategies that accommodate the agricultural resource relatively near at hand. Required procurement of other critical resources will be operationalized by organizing specific resource procurement groups that collect and process the resources and return to the residential base (Binford 1980). These logistically based strategies have differing archeological signatures from hunter-gatherer-based strategies. Increasing agricultural dependence is positively correlated with increasing population density and negatively correlated with levels of mobility (Mauldin 1983:142). In one general way, we can expect greater ranges of intersite variability as a function of increases in the logistical components of the subsistence-settlement system (Binford 1980). Subsistence strategies that tend toward agricultural dependency (for the study area) are found to be archeologically reflected in various lines of evidence, including shifts in settlement patterns, ethnobotanical data, and changes in the ceramic and groundstone assemblages (Mauldin 1986:257-258).

Along the southern and eastern peripheries of the Greater Southwest, relatively sedentary puebloan economies based on small-scale farming give way to more nomadic hunting and gathering economies,....Preserved in the archaeological record of the periphery, and documented in innumerable Spanish archival sources, is clear evidence that the boundary between these seemingly polar

economic and social entities has been anything but sharp, and that over the centuries its nature and position have shifted repeatedly and often dramatically (Speth 1986:xiii).

Ethnohistoric accounts of cultural groups in the vicinity of the study area give us a small window into the past that proves to be useful in terms of observed patterns of subsistence and other behaviors. In the vicinity of El Paso, several cultural groups are mentioned in Spanish documents. These documents from the 1500s through the 1700s give a portrayal of settlement-subsistence patterns of the groups contacted. Settlement and subsistence of groups that are known ethnographically or ethnohistorically point to a mix of subsistence strategies that imply a collecting strategy as opposed to a strict foraging strategy and somewhat lessened mobility (Binford 1980). There are definite indications of populations that are foragers, and they would appear to have symbiotic relationships with other groups that exhibit more mixed subsistence strategies that include relying on some farming (Kenmotsu 1994).

The Patarabueyes, also known as the Otomoacos, and Abriaches were groups who were noted by Luxan in the official diary of the Espejo Expedition of 1582 (for a thorough review see Kenmotsu 1994). These groups were located around the confluence of the Conchos and Rio Grande rivers some 200 miles southeast of El Paso. They were noted through Luxan's rich detail regarding lifeways and cultures. He described the Otomoacos and Abriaches as populous nations, living in adobe houses and farming along the Conchos River up to just above its confluence with the Rio Grande (Kenmotsu 1994:203-208). They were primarily farmers but made much use of wild plants, bison, deer, small game, and fish. They cultivated maize, beans, and squash, and may have practiced a certain amount of residential mobility, as indicated by Luxan's description of the houses they built in the fields, which they occupied during harvest time. They also hunted bison and deer away from their settlements. Meat, hides and other

foraged foods, such as mesquite beans, mescal, prickly pear fruit, and mushrooms, also were an indication of their mixed-subsistence strategies (Kenmotsu 1994:206).

Their dwellings were noted to be made of adobe and were rectangular and semisubterranean (Kenmotsu 1994:206). Archeologically, this structure has been borne out by Kelley's dissertation work completed in 1949 and finally published in 1986. Some of their dwellings were pithouses, made of adobe, and were long east-west tiers of jointed rectangular houses with plazas (Kelley 1986:71-85). The Patarabueyes were seemingly an admixture of Southwestern and Plains traditions.

The Jumanos, according to Kelley's documentary and archeological evidence, were primarily traders and bison hunters. They probably used shellfish and certainly collected wild plants. The agricultural products they had were thought to be acquired through trade with the Patarabueyes. The Jumanos, although centered more in the region of the Pecos River and in Central Texas, interacted closely with a number of peoples living along the Conchos River and at La Junta. The land occupied by the Jumanos was within the historic range of bison, and nearly all researchers consider this nation to have been foragers (Kenmotsu 1994:329). Foraged food included cottontails, fish, nuts, birds, grapes, plums, fish, mulberries, piñon nuts, and tunas, and "the meals that the land will give them (because) they do not sow" (Kenmotsu 1994:329). Jumano camps were located along streams and in rock shelters (Kelley 1986:136). Archeological evidence for tools and other utilitarian items noted by Kelley are evidenced in Trans-Pecos Texas by oval-bowl metates and one-hand shaped and unshaped manos. The Jumanos were known to have been around the El Paso area but their normal range was more to the east and south (see Kelley 1986 and Kenmotsu 1994).

The Sumas and Mansos are mentioned in Spanish documents of the 1600s and 1700s. These two groups were noted to have been in the El Paso area (Forbes 1957:319, 325). Benavides, in 1630,

described these groups as being nomadic and nonagricultural (Forbes 1957:325). They were hunter-gatherers who Benavides described as "warlike, barbarous, and indomitable, because they wander totally nude without house, and without crops; they live from what they hunt, which is all species of animals. . .thus moving from one set of mountains to another" (Kenmotsu 1994:355). It is suspected that in the 1740s and 1750s the Sumas were still nomadic (Forbes 1957:322). An indication of the settlement-subsistence pattern of the Sumas is evident in the comments of Benito, the Bishop of Durango in 1725, when he refers to their "nation which is so extensive that it occupies more than a hundred leagues in circumvallation without any fixed settlements" (Forbes 1957:322). Kenmotsu (1994:333) notes evidence that Mansos were hunter-gatherers. In the Benavides *Memorial*, the Mansos are described as not having houses, "but rather pole structures, nor do they sow. . .but all are nude and only the women cover themselves from the waist down with deerskins." He notes also that they eat rats and fish. Kenmotsu (1994) gives an exhaustive account of the "Indian nations" that could be linked to the La Junta de los Rios, noting settlement-subsistence patterns of each group where possible.

In El Paso del Norte in 1796, Lt. Col. Don Antonio Cordero set down a description of the "Apache nation" (Matson and Schroeder 1957:335-356). The "Apache Nation" Cordero refers to consists of the various groups (he counts nine), "spread out in a vast space of the aforementioned continent (North America) from degrees 30 to 38 of north latitude and 264 to 277 of longitude from Tenerife." According to Matson and Schroeder, the location is quite accurate (Matson and Schroeder 1957:336, footnote #2). Cordero notes that these groups do not compose one nation but posits they are alike in many ways given their various differences in locality, needs, and how much contact they had with the Spaniards (Matson and Schroeder 1957:336). The groups referred to are the Tontos, Chiricaguis, Gilenos, Mimbrenos, Faraones, Mescaleros, Llaneros, Lipanes, and Navajos. In reference to these people, Cordero mentions the "continuous movement in which he

lives, moving his camp from one to the other location for the purpose of obtaining new game and the fruits which are indispensable for his subsistence. . ." (Matson and Schroeder 1957:338). In regard to subsistence, Cordero notes, "besides the meat which is supplied by his continuous hunting and cattle stealing in the territories of his enemy, his regular food consists of wild fruits which his territories produce" (Matson and Schroeder 1957:338). The fruits and game differ in the various regions they inhabit and there are, he notes, some common to all. Cordero provides a list of game animals and food plants that are prepared and consumed by the "Apache." Cordero provides brief descriptions of the process of cooking agave, sotol, and maguey in roasting pits (Matson and Schroeder 1957:338-339). As to settlements:

In general they choose for dwelling places the most rugged and mountainous ranges. In these they find water and wood in abundance, the wild produce necessary, and natural fortifications where they can defend themselves from their enemies. Their hovels or huts are circular, made of branches of trees, covered with skins of horses, cows or bison, and many likewise use tents of this type. In the canyons of these mountain ranges the men seek large and small game, going as far as the contiguous plains; and when they have obtained what was necessary, they bring it to their camp, where it is the work of the women, not only to prepare the foods, but also to tan the skins which are then used for various purposes, particularly for their clothing (Matson and Schroeder 1957:339).

The joining together of many rancherías in one place is usually accidental and comes from all going to hunt for certain fruits, which they know are abundant in such and such a place at a particular time (Matson and Schroeder 1957:342).

The Tarahumara (or Rarámuri, as they call themselves) live in the mountains and canyons of

the Sierra Madre Occidental in southwestern Chihuahua, Mexico, about 450 km south-southwest of El Paso, Texas (Hard and Merrill 1992:602). The Tarahumara are well-known both ethnographically and ethnohistorically (Hard and Merrill 1992:602). Pennington (1963) has made use of the wealth of archival material in Jesuit records along with his personal observations of the Rarámuri. He refers to these people as a semiagricultural folk who were clustered along stream ways of the upland meadows, valleys, and semiarid plains of southwestern Chihuahua. They were scattered over approximately 35,000 km² of territory (Pennington 1983:276).

The Tarahumara region is one with a varied physiography containing steep canyons, uplands, foothills, plains, and basin and range country. Climatically, there is a good deal of variability as well, given the scope of environments present. The area is characterized by seasonal precipitation with summer and autumn being the wettest seasons. Seasonal variability is seen in streambeds that can be swollen in July, August, and September. They have low water during winter and spring, and some smaller streams have only isolated water holes (Pennington 1963:28).

Archeological material, historical records, and recent investigations demonstrate that the basic foodstuffs of the seminomadic Tarahumara have long been corn, beans, and squash. Maize agriculture dominates the Tarahumara economy with approximately 70% to 80% of the diet based on maize (Hard and Merrill 1992:603; Pennington 1963:39, 1983:278-280). These foods were supplemented in the past, as today, by a great variety of wild plant products as well as fish (Hard and Merrill 1992:603; Pennington 1963:39, 1983:280-282). Hard and Merrill describe the residential patterns of these mobile agriculturalists, and as noted above, the Tarahumara derive about 75% of their diet from maize and depend on stored food year-round, yet they shift residences both during the growing season and during the winter (Hard and Merrill 1992:601). The mobility strategies utilized by the Rarámuri inhabitants of Rejogochi (the community and area foci of Hard

and Merrill's research) are viewed from Binford's (1980) hunter-gatherer residential and logistical mobility strategies. The primary type of logistical mobility involves men traveling outside the valley without their families to work for wages (Hard and Merrill 1992:605). Residential mobility includes both the growing season and the winter months. The pattern of residential mobility during the growing season is a product of the use of sometimes widely dispersed fields outside the Rejogochi Valley area. This is due to local principles of land tenure, inheritance, and marriage restrictions. Households care for their fields by moving the residence to the dispersed fields for periods of a few days to several weeks. Often these fields have houses and grain-storage structures associated with them (Hard and Merrill 1992:606-607).

The common residential strategy for winter involves moving all the household members and livestock in December to a nearby rockshelter or another house where they stay through February. Rockshelters are the preferred winter residence. This preferential form of residence has its beginnings in prehistory (Pennington 1963:221-223; 1983:287) and continues into the present. They are generally located in the walls of small canyons off the main Rejogochi Valley. Rockshelters remain dry, usually have a southerly exposure, and receive direct sun much earlier than the valley bottom. They are usually located closer to firewood than the valley homes and some have springs located nearby. Most of these rockshelters are large enough to accommodate the family's sheep and goats on one end in a corral with low stone or log walls used as windbreaks and to divide sleeping and cooking areas at the other end (Hard and Merrill 1992:607-608).

Hard and Merrill's analysis of growing-season mobility strategies employed by the Rarámuri indicate there are three conditions that appear to motivate these patterns. Residential mobility at dispersed fields as opposed to logistical mobility is motivated first by the need to stay at the fields for extended periods of time; second, by the existence of tasks that require the attention of both men and

women at distant fields, and third, by the need to consume the harvest there instead of transporting the crop back to Rejogochi (which does occur on occasion to replenish depleted supplies) (Hard and Merrill 1992:609-613). In the case of dispersed or fragmented fields, it would also appear that these are maintained to produce additional yields of maize and to offset extremes of microclimatic variability (Hard and Merrill 1992:609-612).

As to winter residential mobility, the strategy most commonly employed is that an entire household will move to a rockshelter, or sometimes, a house. This residential move involves a moderate labor expenditure since food must be periodically transported to these shelters from their valley homes. However, this residential move oftentimes reduces risk of losing animals due to exposure and affords all family members the benefits of rockshelter living (i.e., warm, dry surroundings with convenient sources of firewood) (Hard and Merrill 1992:613-614). As Hard and Merrill point out,

It is clear that neither mobility nor sedentism is an inherently better settlement strategy. Simply assuming that direct correlations exist between economic and settlement systems is counterproductive, because doing so precludes examining the basic issue of why one pattern exists rather than another. Different mobility strategies represent alternative solutions to the problem of bringing people and resources together in space and time (1992:616).

This case points to the fact that our biases regarding settlement patterns and subsistence pursuits must be reigned in and our scope of strategies toward social and economic structures and their optimum use of the environment broadened.

The Western Apache are a group that practiced a mixed strategy of hunting/gathering and some agriculture. They utilized vast areas of territory. The approximately 90,000 square miles of their territory contained extreme ecologically diverse

landscapes, from high mountains to arid deserts. These were the environments in which they subsisted by hunting and gathering (Basso 1983:462-488). Their dependence on some agricultural products such as corn, beans, and squash, lessened only to a degree their high mobility (Buskirk 1986; Perry 1991; Pool 1985). Pool (1985) utilized the prereservation period settlement system taken from ethnographic accounts as a potential analog for the Early Mogollon period. This model characterizes the early period as semisedentary with a mixed subsistence strategy ranging over vast areas.

The Mescalero Apache cultural group is significant in that their range includes the study area and was most considerable, encompassing approximately 100,000 square miles. Their territory was bounded on the west by the Rio Grande, and by the Pecos River on the east well into Texas. On the south, they ranged well across the Rio Grande into the present Mexican states of Chihuahua and Coahuila (Opler 1983:419). This vast territory was not conducive to large and concentrated populations. Topographically, their territory varied from 12,000 ft high mountains (Sierra Blanca) to hot and dry desert areas, such as the Tularosa Basin and Hueco Bolson, and the Organ Mountains to the west of the Bolson. This variation of climate and topography influenced their settlement and subsistence patterns. Their subsistence activities, population concentrations, and movements were conditioned to a considerable degree by available water supplies (Basehart 1973:172). They were traditionally hunter-gatherers who were spread out over their vast territory in small groups (Opler 1983:420). The geographical distribution of plants and animals that formed the basis of their subsistence required them to use vast areas of their territory. Also, both plants and animals were subject to periodic fluctuations in quantity so that different locations within the Mescalero territory afforded variable opportunities for subsistence from year to year (Basehart 1973:147-148). Cordero noted,

They change their *rancherías* when, in the place in which they have been living, the

foods necessary for them and their beasts become scarce, moving now from one mountain range to the other, now from a rock or cliff to another of the same range or mountain. Of much influence in these moves is the necessity of seeking places for the purpose of passing the different seasons of the year with more comfort" (Matson and Schroeder 1957:342).

The Mescalero Apache in prehistoric times most likely practiced very little agriculture; Cordero mentions, "they were known to cultivate a few crops such as corn, beans and squash and tobacco, which the land produces more on account of its fertility than for the work which is expended in its cultivation" (Matson and Schroeder 1957:338-339). Their limited efforts at agriculture exerted little influence on the hunting and gathering mode of the majority of Mescaleros (Basehart 1973:174).

The hunter-gatherer groups noted above have similar high mobility signatures. These highly mobile patterns of subsistence and settlement are a reflection of the variable nature of their respective environmental settings. Archeologically, these coping strategies generally have a low visibility factor given the necessity of the groups small numbers, the essential material possessions, and the frequency of moves. Groups noted above that practice some form of agriculture relinquish some of their mobility due to the investment of time required to insure successful crops. However, the highly variable nature of semiarid environments require the flexibility within the system to maintain a certain amount of mobility that enables those groups to successfully meet their subsistence needs. Nowhere in the Southwest were villages (especially early periods) sustained entirely on agricultural produce (Cordell 1984:215). Archeologically, the hunting-gathering strategies employed, along with farming, should have a different and more visible signature than simply a hunting-gathering strategy. These adaptive strategies require storage of food products, a more complex or varied set of tools, and habitation sites that allow for larger groups conducting varied tasks for longer periods of time.

In discussing the land use of an agricultural economic system in an arid to semiarid environment, it is important to reiterate the supposition that nowhere in the Southwest were villages (especially during the earlier periods) sustained entirely on agricultural produce (Cordell 1984:215). Mixed subsistence strategies, necessitated by the vagaries of an arid environment, have been documented both ethnohistorically (Kelley 1986; Kenmotsu 1994) and ethnographically (Basehart 1973, Buskirk 1986). Farming and hunting and gathering are strategies that are utilized in concert to meet subsistence needs. Adaptive strategies utilizing farming technologies result in certain effects upon both the environment and human groups. Farming, by its nature, has a tethering effect upon its practitioners. Crops require water, which has a tethering effect on the placement of those resources. Crops must be planted in soils that have an appreciable moisture content and located where water is available as a reliable source through rainfall runoff or some constructed device allowing for the watering of plants when needed. Another tethering effect of crops is the investment of time in one area to care for the plants and their success. Longer stays necessitate more substantial and permanent habitation structures. Farming requires larger numbers of individuals to prepare soil, and plant and harvest crops. Larger groups or aggregates of people remain (at least a portion of the time) in the same area. Larger groups necessitate a substantial investment in storage for excess of crops not consumed immediately after harvest. Territoriality becomes more of an issue as investment of time and labor for crops becomes necessary.

Climatic instability of arid environments necessitates relying on other resources as a proportion of diet. Hunting is a means of procuring meat and hides and other byproducts of animals for subsistence. Gathering alternate plant foods adds variety to diets and/or replaces depleted crop resources through a season. Wild plant foods are also sources of fiber and materials used for things other than food (e.g., medicine) (Castetter and Underhill 1935; Castetter and Opler 1936). A

mixed subsistence requires scheduling of alternate procurement strategies such that they are accomplished around the farming schedule. This implies alternate strategies involving differential groups dedicated to target resources in particular procurement zones within the available environmental territory. All environmental zones are utilized in the pursuit of a mixed subsistence strategy, just as they are in a hunting-gathering economic system; however, they are utilized in different ways, thus their use presents a different archeological signature (Binford 1980, 1982).

8.4 SYNCHRONIC MODELS FOR FORT BLISS AND THE SURROUNDING AREA

Due to the sampling and systematic survey of thousands of square kilometers of Fort Bliss lands (Beckes et al. 1977; Carmichael 1986a; Skelton et al. 1981; Whalen 1977, 1978) several land-use models have been developed since at least 1980 with regard to the area of west Texas and south-central New Mexico. These have been developed as heuristic devices to organize and integrate research and include or are specific to the Fort Bliss area (Anderson 1993; Hard 1983a; Hard and Mauldin 1986; Mauldin 1986). Hard (1983a) and Mauldin (1986) have both utilized generalizations, taken primarily from Binford (1980) regarding resource acquisition and mobility strategies utilized by groups that are primarily hunters and gatherers. An important premise remembered here is that environmental variability and adaptive mobility strategies are inextricably linked.

For hunter-gatherers, the most critical strategy for obtaining the necessities is mobility. Resource availability in an arid environment is highly variable both temporally and spatially. That is, in an arid environment the types and amounts of resources will change from year to year (and season to season); and there will be changes in the location or types of location of resources (Jochim 1991:311-312). This factor of high environmental variability is dealt with through adaptive strategies of flexibility, opportunism, and variability. Effective strategies of mobility require efficiency in movement, best accomplished through small

numbers of individuals working as a unit with few possessions. Consuming the acquired resources on a day-to-day basis creates no need for storage, thus reinforcing the effectiveness of high mobility.

Hard and Mauldin (1986:45) stress the necessary interplay between the models of regional systems they present and the development of unambiguous methodologies that can address relevant aspects of those models. The models identify which behaviors are relevant and critical for an overall evaluation. They serve to differentiate what is interesting and possible from what is relevant and necessary (Hard and Mauldin 1986:45). The southwest in general has a considerable body of data for the Archaic period. Simmons et al. (1989) indicates that the majority of these data come from northwestern New Mexico. Most of the various models developed for the Archaic rely on a consideration of subsistence strategies as site distribution determinants (Simmons et al. 1989:39-74). Mauldin (1993a:15) notes (in regard to the Fort Bliss area) that attempts to develop criteria recognizing elements of different cultural systems have focused on variability in site location, ceramic assemblages, groundstone assemblages, architecture, faunal remains, and some lithic assemblages.

Land-use patterns of late Pleistocene (Paleoindian) hunter-gatherers are not as well-known in the study area as later economic adaptations of hunter-gatherers. A consideration of the environment is critical to understanding the earliest hunter-gatherer adaptations. Plant macrofossils in ancient packrat (*Neotoma* spp.) middens document the presence of woodland communities in most of the present Chihuahuan Desert during the late Wisconsinan (22,000 to 11,000 BP by radiocarbon dates) (Van Devender and Spaulding 1979:701-710). During this time, a piñon-juniper-oak woodland covered the rocky slopes 600 to 1,675 m, the entire elevational gradient of what is now occupied by Chihuahuan Desert in the United States (Van Devender 1990:120). Presumably during the late Wisconsinan, the playas supported pluvial lakes (Van Devender 1990:121). Inferred mild, wet winters and cool summers produced unusual plant

and animal associations compared to modern times (Van Devender and Spaulding 1979:701-710). These environmental factors would have drawn hunter-gatherers through the area (Carmichael 1986a:41-42). There are numerous playas on the basin floor within the bounds of the study area (see Figure 2.1). These playas, given the wetter, cooler conditions during the late Pleistocene, may have held enough water to support short-term hunting and/or gathering camps. These playas may have acted not only as a source of water for both hunters and animals, but may have been utilized by the hunters as traps for the water-seeking animals (Judge 1973:195-197). The hunter-gatherers may have used these elements in opportunistic ways. Carmichael (1986a:211) notes no evidence of sites that could be considered "base camps," as Judge (1973:199-201) refers to them. There may be those types of sites meeting all of Judge's criteria outside Carmichael's study area, Maneuver Areas 3 through 8, to the west along the Rio Grande or to the north in the area of the Jarilla Mountains and the Three Buttes area to the northwest (Carmichael 1986a:211-212).

As a general characterization, Paleoindian hunter-gatherers formed themselves in small, highly mobile groups ranging over large territories in pursuit of game. These hunter-gatherers manufactured specialized tools, such as fluted points (Folsom points), which are found in association with now extinct megafauna. Most tools that have been recovered are appropriate for felling and butchering game, for processing hides, and working bone and wood (Carmichael 1986a:7-8; Cordell 1984:142-143). Plant foods were gathered and utilized as well. However, the degree to which these were incorporated in the earliest economies is not known (Cordell 1984:145), especially in this area.

The Archaic, as Cordell (1984:154) notes, is a term that refers to both a period of time and a way of life. The period of time follows the Paleoindian from approximately 6000 B.C. to A.D. 100. As a way of life, or an economic strategy, it is characterized as a continuation of hunting and gathering. There are, however, significant changes

observed archeologically in hunting and gathering strategies that serve to differentiate the Archaic peoples from their Paleo-predecessors. These differentiations are due to environmental changes that were on a global scale. The warming trends that brought the Pleistocene to an end caused widespread vegetational and faunal changes (Clark 1977:10-18). The adaptations to these changes were global in scope as well; however, the area which we will be dealing with is the arid environment of the Southwest, the Chihuahuan Desert in particular. Environmental indices dating from the late Wisconsinan glacial maximum (22,000 to 11,000 BP) document the occurrence of pinyon-juniper woodlands at middle elevations of 1,525 to 550 m in areas now occupied by desert scrub communities (Van Devender and Spaulding 1979). The end of the Pleistocene and the beginning of the Holocene (11,000 to 8000 BP) was evidenced by the presence of a xeric woodland; an inferred winter precipitation regime persisted until about 8,000 years ago (Van Devender and Spaulding 1979). The present climatic and vegetational regimes were established after about 8000 BP. A reduction of winter precipitation and a concomitant increase in summer precipitation in present monsoonal areas was inferred from a synchronous, well-documented climatic change that resulted in the elimination or reduction of woodland elements from the Mojave, Sonoran, and Chihuahuan Deserts about 8,000 years ago. This event may record a shift to a summer rainfall desert-grassland regime in the northern Chihuahuan Desert (Van Devender and Riskind 1979:138).

The adaptive strategies of Archaic groups include a greater reliance on plant foods, as evidenced by the presence of small grinding stones to process those plant foods. The animals sought by these groups are all modern species. The other tools utilized reflect a more generalized economic strategy. Land use of these groups is seen also as more generalized. That is, Archaic-aged sites are found in all environmental zones. The previous discussion of hunter-gatherers, their needs, and their risk-reducing strategies to satisfy those needs through high mobility, are applicable here. An

important event in the Late Archaic was the introduction of cultigens in the area. Little immediate impact upon Archaic lifeways was probably seen. However, during subsequent adaptations, cultigens played an increasingly important role.

Hard's (1982) development of a cultural-ecological model for the El Paso area was primarily directed at the Mesilla phase. O'Laughlin (1980:146) saw little marked divergence in subsistence-settlement patterns between the Archaic period and the Mesilla phase, and noted that changes occurred in a gradual fashion over a long period of time.

A general model for the Archaic and early Formative occupation and use of the basin floor has been developed by Hard (1982). He proposes that the basin floors were used most intensively during the mid to late summer when basin resources (plants, animals, water) are at their peak availability. Hard contends that a foraging strategy probably was employed in which people moved from water source to water source, exploiting the adjacent food resources. Playas would have served as the water sources in the basins. He suggests camps were occupied for short periods, not more than a few days to a few weeks. This land-use system would have required little investment in housing and storage facilities (Foster 1993:64).

Archaic period land-use patterns were posited by Anderson (1993:48-67). Anderson divides her study area (Maneuver Areas 3-8, (Carmichael 1986a) on Fort Bliss and sites from the Rio Grande and surrounding mountains) into landform areas: desert floor, low and high alluvial, mountain, and riparian. Anderson utilizes 156 of the 240 sites from Carmichael's 1986 survey and places them in one of MacNeish's (MacNeish and Beckett 1987) Archaic phase designations: Gardner Springs (6000 to 4000 B.C.); Keystone (4000 to 2500 B.C.); Fresnal (2500 to 900 B.C.); and Hueco (900 B.C. to A.D. 250). Anderson locates these sites with respect to the above-mentioned landforms and

also assigns each site in one of the following four categories. The *macroband* category defines sites that have four or more hearths or large amounts of groundstone. The *microband* is distinguished by one to three hearths. Although sites in the *task force* category usually lack hearths, occasionally one may be present. Finally, Anderson includes, but does not define, *base camps*. These apparently have structures and are more intensively occupied than macrobands. They may represent occupation through one or more seasons in a year. Given all these data, Anderson describes the land use for each phase. The Gardner Spring phase (6000 to 4300 B.C.) had a seasonally nomadic subsistence system with no base camps (as such), but moved constantly, with the pattern dictated by seasonally available resources. She posits that during the Keystone phase (4300 to 2600 B.C.), the settlement pattern is similar, but at the Keystone Dam sites at the end of the phase evidence of a pithouse signals a shift to a system of base camps and special activity sites. The Fresno phase (2600 to 900 B.C.), given the data at Keystone Dam, suggests the use of base camps and/or multiseasonal use of the Rio Grande area with special activity camps in other environmental zones. The implication of changing technology and subsistence bases is seen through greater numbers of grinding implements, cultigens, and the placement of sites on alluvial slopes. Anderson sees the continuation of these patterns in the Hueco phase (900 B.C. to A.D. 250). Anderson (1993:67) also notes that this trend seems to continue into the ceramic Mesilla phase.

Hard's (1983b) model for the Late Mesilla phase (A.D. 750 to 1100) proposed that functionally differentiated sites existed during the Late Mesilla phase due to changing seasonal resource availability. Responsive to this variability, at least two types of residential sites were suggested to have been in use during the Late Mesilla phase: summer-foraging and winter-collecting base camps. Seasonal environmental variability and the related changes in land use and residential sites were taken into account (Hard 1983b:41-51).

Mauldin (1986) presents a model of land use during the Pueblo period (A.D. 1150-1400) as an extension of Hard's model in the Fort Bliss/El Paso region. His model focuses on resource acquisition and mobility strategies employed by Pueblo period populations. Two major residential types, primary and secondary habitation sites, are postulated. Mauldin considers primary habitation sites to be well-watered locations, principally the mountain slopes and river margins, which were occupied throughout the year. Agriculture was considered a major activity at those locations. He considers logistical forays, primarily deer hunting and plant collection, to have been launched from those primary site locations. Secondary sites, located in the same zones as primary sites as well as in the central basin, were those probably occupied only during the summer after the initiation of the summer rains and before the harvesting of the agricultural crops at the primary village sites; foraging for seasonally available plants and animals was the focus of activities at the secondary sites. The site types and their expected characteristics are considered (Mauldin 1986:255-269).

Hard and Mauldin (1986:3, 13) focus on land-use models for the late Pithouse (AD 750 to 1100) and Pueblo (AD 1100 to 1400) periods in far west Texas and southern New Mexico (mostly Fort Bliss). They developed these models of how these cultural systems may have operated in order to reconstruct individual settlement components and relationships between them. Two major residential locations, winter and summer sites, are proposed for the late Pithouse period and two major locations, primary and secondary sites, are discussed for the Pueblo Period (Hard and Mauldin 1986:14).

The annual cycle is divided into general categories of wet and dry seasons. This division accounts for the major expectable differences in settlement and subsistence patterns, not the total seasonal variability or related prehistoric system shifts in the region (Hard and Mauldin 1986:16).

The land-use models presented above were developed to provide frameworks in which further investigations could be conducted. They are a partial response to the lack of developed methods that could allow accurate identification and interpretation of site variability within the El Paso region. These models are set within the culture-historical framework of phase and/or periods, and they assume lesser or greater dependence upon agriculture (Hard 1983a:9; Mauldin 1986:257). They deal with environmental variability and propose that functionally differentiated sites existed during particular time periods due to changing resource availability (Hard 1983b:44; Mauldin 1986:257-258). Also, both Hard and Mauldin's models allow for a mixed subsistence strategy given the vagaries of the semiarid environment. These mixed strategies are viewed within the same cultural and adaptational system.

8.5 ADAPTIVE DIVERSITY - ALTERNATIVE EXPLANATIONS

Other researchers have posited that there is evidence for a dual subsistence-settlement system, one in which sedentism and mobility are both characteristic, and at some points, contemporaneous cultural patterns in the area (Upham 1984:235-256; 1994). Upham suggests that data identifying the kind of adaptive diversity above have already been collected by archeologists. He refers here to limited-activity sites, or artifact scatters. These sites are identified and assigned a temporal and cultural affiliation on the basis of ceramics or diagnostic lithic material without clear understanding of their structural relationship to the settlement-subsistence system (Upham 1984:239).

Carmichael (1986a:239-253) discusses the discovery of ephemeral residential structures dated to the Pueblo period (AD 1100 to 1400) in the west El Paso area. He notes that the characteristics of the houses and the artifact assemblage suggest that they functioned as a short-term base camp in an adaptive strategy of high residential mobility. The late dates imply that such a mobile strategy may have been in operation during the same general period as more logistically organized,

pueblo-based, adaptive strategies. Carmichael suggests that there is a need to cope with the potential for identifying "Archaic-like" adaptive strategies at other times besides the Archaic Period. He further notes that, "Many late foraging sites have probably been misidentified as preceramic sites, or as logistic camps associated with one of the Formative phases" (Carmichael 1986a:253). Carmichael (1990:122-134) notes that present data suggests that sedentism appeared later in the Jornada area (A.D. 1100) than in other parts of the Southwest. He also notes that there is evidence that sedentary strategies were not sustained for long periods, even during the Pueblo period and, "The coexistence of, or oscillations between, mobile and sedentary strategies may be indicated" (Carmichael 1990:122).

Young (1994:141-154) takes Upham's (1984) proposition that prehistoric populations frequently oscillated between mobile and sedentary adaptive strategies and his argument of limited-activity sites as the remains of hunter-gatherers rather than sedentary agriculturalists. She suggests that differences in lithic technology provide a better method for distinguishing the remains of highly mobile groups from those of sedentary populations. Young examined the methodological problems she saw in Upham's arguments but affirms the correctness of his calling attention to the diversity of adaptive strategies within the Southwest (Young 1994:152).

Upham's model of adaptive diversity predicts that oscillation between adaptive strategies by different southwestern groups was common after 1250 BP (1994:157). He notes that, "some archeologists have chosen to focus on the economic relationships between gatherer/hunters and village agriculturalists during this and the immediately preceding time periods and have generated some very interesting results (e.g., Spielman 1991a, 1991b)" (Upham 1994:157).

Kenmotsu (1994), undertaking the study of the interaction between small-scale foragers and cultivators, develops a model of mutualistic interaction and tests the model with data contained

in Spanish documents dating from A.D. 1545 to 1750 that relates to the La Junta de los Rios region of Mexico and Texas. She notes that there is abundant documentary evidence of the existence of close relationships between the nations of La Junta de los Rios and the foraging nations that occupied various territories around the Presidio Bolson. There is substantial documentation that these interactions were based on relationships that had been in existence for a long time and that they were activated during periods of stress, such as war and famine (Kenmotsu 1994:509).

If indeed there are competing adaptations and/or mutualistic interactions between hunter-gatherers and agriculturalists across the landscape, then we must devise workable methods that allow us to ascertain the true context and function of any archeological sites, let alone limited-activity sites. Land-use models can accommodate those suppositions by altering the hypotheses so that we can find viable methodologies that will identify and come to terms with the archeological record and the explanations we seek.

The function of any of these models is to provide a framework upon which to ask questions, to test assumptions, and to develop alternative hypotheses or ways of addressing the data. In order to test implications inherent in these models the data must contain spatial and more importantly temporal boundaries (Carmichael 1986a:21). Surveys conducted on Fort Bliss (Beckes, Dibble, and Freeman 1977; Carmichael 1986a; Skelton, et al. 1981; Whalen 1977, 1978) have documented thousands of small artifact scatters or isolated features that cannot be assigned any temporal placement (Mauldin 1994:1). Seaman et al. (1988) and Doleman et al. (1991) encountered similar occurrences to the north in the Tularosa Basin. Mauldin (1993a) points out that the "temporally unknown" sites with their low artifact inventories, small size, and low frequency of diagnostics are not generally the focus of archeological investigations. However, some work has been accomplished on these types of sites (Whalen 1980, 1986; O'Laughlin and Martin 1989; Doleman et al. 1991; Mauldin, Graves, and

Bentley 1994). The work of Mauldin, Graves, and Bentley (1994) suggests that there are different patterns of behavior within the basin, suggested by two dating techniques, radiocarbon and obsidian hydration (Mauldin, Graves, and Bentley 1994:XIV). One is a hunting-gathering, high-mobility residential pattern (short-term residences), and the other, later in time, is a use of the area as foraging zones or locations for resource collection (logistical strategies -- Binford 1980). Often these small sites or features are relegated to the Archaic period due to a lack of temporally diagnostic materials -- we assume an association given the lack of data. Ironically, we often assume an association for a whole site due to a temporally diagnostic artifact or sets of artifacts. Given the dynamic nature of the environment, it is dangerous to assume temporal associations for whole sites when we have a palimpsest of data that defies separation into obvious temporal periods based on our present cultural-historical context.

We must develop methodologies that will allow us to understand the associations of the cultural materials we have on record and that we continue to discover and record. We can only advance our comprehension by continuing to acquire solid chronological data for as much of the material as possible. Without detailed attention to and the understanding of the chronometric factors, as well as the associations of materials within features and sites, we cannot bring together the vast amount of archeological data into a substantive picture of the past, let alone assess the significance of that data.

8.6 RESEARCH QUESTIONS

As mentioned previously, data needs for this research domain are sought out on different levels or scales (e.g., intrasite, intersite, and regional). In order to meet cultural resource research and management needs, many of the questions concerning past cultures on Fort Bliss involve and revolve around the highly dynamic environment on the post. Many of the geomorphic processes that impact archeological resources on the post must be understood and accounted for within the context of the cultural processes we seek to understand,

explain, and manage. Recent studies (Mauldin, Graves, and Bentley 1994) have indicated that research at the "site" level may not be the most appropriate analytical unit. With that in mind, we should seek and refine other differential scales of analysis. Three critical factors that make the study of settlement patterns helpful to an overall picture of adaptive behavior and culture change are time, space, and function. In order to define a settlement pattern, we must discover the temporal and functional distribution of site placement. These three factors are critical at other levels of analysis. Research questions at every scale incorporate, in some way, temporal, spatial, and functional considerations.

Figure 35 illustrates the effect of closer survey transects. Site distribution becomes a factor of geomorphic process, visibility, and survey coverage. The need to reassess the already-surveyed areas, especially those from the beginning (Whalen 1977, 1978), and areas where only percentages of areas were covered (Beckes et al. 1977; Skelton et al. 1981) is indicated when one looks at the site distribution as shown on the map.

8.6.1 Questions at a Geomorphic Scale

As we have noted previously, a variety of geomorphic schemes have been used to classify landforms on Fort Bliss. The most detailed scheme is that of Satterwhite and Ehlen (1980), who identify four primary landforms (mountains, alluvial fans, basin areas, and washes) and subdivide these into 13 secondary forms. Here, we use a six landform scheme modified from Hard and Mauldin (1986) and from Monger (1993a). These landform units are: the *Central Basin Playas*; the *Basin Floor*; *Alluvial Fans*; *Otero Mesa*; *Uplands*; and the *Riverine Zone*. These landform units are depicted in Figure 3. Below, we describe them individually, noting where our terminology differs from that used by Hard and Mauldin (1986) and Monger (1993a). The six landform units are then followed by a single set of research questions and data needs which are common to all.

8.6.1.1 Central Basin Playas

This geomorphic unit contains the playas and areas enclosed by an arbitrary one-mile radius around them. The use of a one-mile radius is an arbitrary, albeit conservative, acknowledgment that mobile societies commonly utilize a peripheral area around a tethered resource such as a playa. Lee (1968:35) noted that the !Kung San obtained most of their food within a two hour walk, which is roughly equivalent to a six-mile maximum radius. The one-mile radius is thus a conservative figure which represents a 20 minute foraging pattern around a playa, and which will include most, though not all, of any special purpose sites which may be functionally linked to the playa. The playa depressions dot the central basin at Fort Bliss. The Central Basin Playas unit corresponds to Monger's Youngest Basin Fill landform and Hard and Mauldin's Basin-Playa zone. Past studies indicate this zone exhibits two different functional uses through time. The tendency is for earlier residential sites (foraging sites -- shorter-term residences) and later short-term special purpose camps (logistical sites -- targeted resource collection sites) to be associated with this landform.

8.6.1.2 Basin Floor

This landform designates the Hueco Bolson. The bolson is generally homogenous and is covered by coppice dunes, eolian sheet deposits, and areas of deep sands and sparse interdune areas. It includes all nonplaya areas of the basin. The bolson corresponds to Monger's La Mesa Basin Floor, Dunes, and Fault Complex landforms and Hard and Mauldin's Central Basin zone.

8.6.1.3 Alluvial Fans

This geomorphic unit comprises proximal and medial areas of alluvial fans, interfan valleys, and coalescent fans or bajadas. This zone, which is generally about five miles wide, and in places abuts several of the larger playas such as Old Coe Lake. This zone corresponds to Monger's Fan-Piedmont landform and Hard and Mauldin's

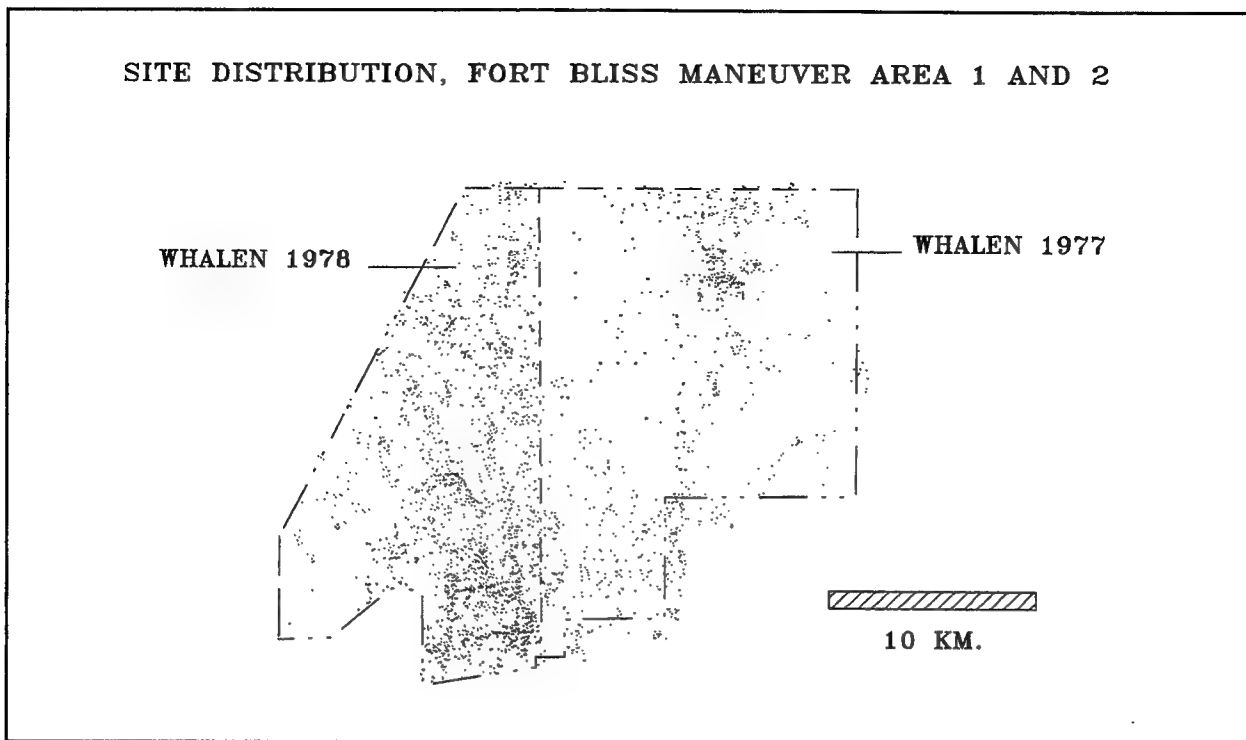


Figure 35 Site Distribution, Fort Bliss Maneuver Areas 1 and 2.

Mountain Periphery zone.

8.6.1.4 Otero Mesa

This landform is a level to rolling tableland, a gently eastward-sloping homocline with a similar north-south trending escarpment and pediment on the western side (Kenmotsu and Pigott 1977:99) (see Figure 2). Satterwhite and Ehlen (1980:49) note Otero Mesa as a landform subunit. They include several large buttes similar to, but separate from, the Otero Mesa which is situated in the northeastern portion of Fort Bliss called McGregor Guided Missile Range. A sample survey was conducted over the 1,090 square mile area covering McGregor (Beckes et al. 1977). Six quadrants of 36 square miles each were established over the major ecological and topographic zones of McGregor Range. Otero Mesa was included in portions of quadrants V and VI along with spot checks performed on the mesa. A total of 216 square miles or 20%, was intensively examined, and another 15% of the total range was covered by the spot check portion of the program. A total of

414 prehistoric sites were recorded on McGregor Range during the sample inventory. One archeological site was tested on the Otero Mesa portion of the range. As to broad temporal designations: of the 48 sites recorded within the Otero Mesa physiographic zone, all sites, with the exception of one (n=1) Archaic-aged site, have either an estimated age given as Formative (n=33) or Unknown (n=14). The site types defined by Beckes et al. (1977:34-40) range from limited activity loci, (i.e., burned rock loci with or without ceramics, isolated hearths, isolated bedrock mortars, and isolated ceramic scatters) to habitation sites (i.e., village complexes with ceramics, complex camps with or without ceramics, and rockshelters). Monger's study did not include McGregor Range. Hard and Mauldin include Otero Mesa in their Mountain zone.

8.6.1.5 Uplands

This landform includes the bedrock uplands and occurs on Fort Bliss in the Organ, Franklin, Hueco, and Sacramento mountains. Bedrock landform is

the name which Monger applies to this zone, while Hard and Mauldin refer to it as the Mountain zone.

8.6.1.6 Riverine Zone

This environmental zone is not present within the boundaries of Fort Bliss and is not depicted in Figure 3. However, it is comprised of the Rio Grande drainage, floodplain, and adjacent areas. Although this environmental zone does not occur on post, it is critical to the area as it is the only permanent source of water in more than the southern half of the post. Monger has no equivalent. Hard and Mauldin refer to the same named zone.

- 8-1 What are the types of sites or cultural event loci and what spatial patterns exist within these?
- 8-2 What functions occurred at these sites or event loci, and do the range of activities differ between zones?
- 8-3 Is there any relationship between the presence of surface structures and zone?
- 8-4 What are the differences between the assemblages earlier (foraging) residential manifestations and later logistical camps?
- 8-5 What pattern of material remains exist on subunits within the landform (e.g., ridgetops), and can these subunits be treated as analytical units?
- 8-6 During what seasons was the landform occupied or exploited?
- 8-7 Can post-depositional transforms (e.g., erosion) be identified and can these contexts controlled for?
- 8-8 What links can be made between the assemblages of sites in different zones?

Data needs: Within each landform, 100% inventory coverage within sampling units will

provide needed site distribution data; closer order transect spacing will provide more comprehensive information about the smaller and/or more ephemeral sites. Excavation should be targeted at obtaining macrobotanical samples, faunal assemblages, and a representative index of lithic tool diversity. Because Fort Bliss has no lands within the Riverine Zone, additional site distribution data is not possible, but supplementary data may be obtained from off-post studies conducted within the region.

8.6.2 Questions at the Site or Intersite Scale

The archeological site has long been the scale at which research (and management) has taken place. As mentioned previously, recent research (Mauldin, Graves, and Bentley 1994; Camilli 1988) has suggested that the site level may not be an appropriate analytical unit to successfully investigate variability in temporal, functional, and adaptive differences. As a practical matter, the site concept is unlikely to be replaced because archeological resources on federal installations must be explicitly defined and spatially delimited in order to be managed. Nonetheless, this requirement does not preclude the non-site analysis of archeological data for the purposes of discovering patterns which might be obscured by our etic construct. Research at this scale needs reevaluation.

- 8-9 Which analytical scale(s) is most appropriate for each research domain?
- 8-10 How do small sites fit into a settlement pattern?
- 8-11 How do big sites fit into a settlement pattern -- can multicomponency be accounted for?

Data needs: Sampling units with 100% survey coverage, using constant transect intervals, are needed. Within these, multiple chronometric assays are needed to control for and identify multiple componency.

8.6.3 Questions at the Intrasite Scale

Much of the archeological information from which we define "sites" comes from analysis of cultural remains at the intrasite level. In order to look at the materials to get at questions of variability in time, function, and adaptive differences, we must pursue smaller analytical scales, such as features and artifact variability.

- 8-12 Can finite measurements be adopted on such features as hearths, storage pits, or structures to insure appropriate associations with artifacts?
- 8-13 Can (and if so, how) dates on features and/or assemblages be positively determined as mutual?
- 8-14 Can geomorphic processes be factored in or out to allow for determining either true multicomponentcy or palimpsest conditions?
- 8-15 Can discrete artifact clusters be separated and defined?
- 8-16 Can a sourcing of materials and a distinction be made between formal and expedient tools found in the study area?
- 8-17 Can temporal separation of artifact clusters be achieved?
- 8-18 Can functional separation of these clusters be achieved?
- 8-19 Can geomorphic processes such as erosion and deposition be accounted for or factored out?
- 8-20 Can issues of mobility and adaptive strategies be discerned by analysis of ceramics?

assemblages that may or may not be associated with any particular patterns. We must look for consistencies in patterning at this level of inquiry over large-scale areas. Artifact clusters need to be considered as an appropriate analytical scale. A database of information regarding clusters, such as temporal, functional, and resource location for artifactual materials, must be compiled. Consistencies in patterning at this level of inquiry is necessary to answer questions at larger scales. Additional data should be compiled on lithic material sources, tool types, and any patterning that might indicate preferences for particular tool types and materials available or not available in the study area. Data compilation should continue on sourcing of clay materials in the study area and other analyses on ceramic wares in the study area. To pursue the idea of differences in adaptive strategies through time within the Central Basin, additional (as many as possible) C¹⁴ and obsidian hydration dates should be compiled in as much of the study area as possible.

Data needs: It will be necessary to compile profile data on features such as hearths: structural patterns (i.e., shape and depth), particular

9.0 SUBSISTENCE RESEARCH DOMAIN

Raymond Mauldin

This chapter presents background on subsistence issues within the study area. After a review of biological and artifactual data sets that may be applicable to investigations of subsistence, a series of general research questions are outlined that are applicable to regional, intraregional, site, and intrasite levels. Data needs that are required to effectively investigate these questions are identified at a general level. This is not an overview of subsistence in the Jornada, nor is it a detailed review of all previous investigations in the region. Rather, our goal is to provide sufficient background information on data groups, identify gaps in current subsistence research, and outline research that will begin to close those gaps.

9.1 APPROACHES TO SUBSISTENCE ISSUES

Investigating and explaining subsistence organization within the research area logically involves:

- (1) the identification of resources used at various times and places within the region;
- (2) developing a description of the mobility and technological strategies used to acquire those resources;
- (3) documenting changes in those mobility and technological strategies; and
- (4) developing explanations for those changes.

Here, we are primarily concerned with the first of these four steps, for it is necessary to answer this question before we can proceed to the higher levels. Note also that progress in subsistence research is closely linked to progress in a variety of other research realms, including paleoclimate reconstruction, chronology, and technology.

Given the theoretical perspective of cultural ecology that guides this research, documenting

subsistence, both through investigations into technologies used in processing resources and in the recovery of more direct evidence derived from biological data, is a critical component of this research design. It is in this realm, where cultural adaptation interacts with the paleoenvironment, that adaptive strategies are created. In addition, changes in those strategies are a result, to a large degree, of interactions at this cultural and natural interface. Changes in subsistence are brought about by the interaction of factors such as the introduction or development of new technologies, changes in the availability of prey items, seasonal shifts in the dietary quality of those items, and long-term shifts in availability of resources. Subsistence decisions, then, comprise a critical element in human adaptations, impacting technology, settlement strategies, mobility levels, seasonality, and the overall cultural organization.

The initial factor in structuring subsistence involves the available resources, their relative density, and changes in those resources both seasonally and at longer time scales. The resource structure, then, defines what we will refer to as an economic landscape. Most aspects of the economic landscape in the current study area is, at a macroscale, associated with the Chihuahuan Desert. Recent research by Monger (1993a) supports VanDevender's (1990; VanDevender and Spaulding 1979) arguments that most elements of the Chihuahuan Desert community that currently dominates the region were essentially established during the period between 9000 and 6000 BP, and that by 4000 BP the modern Chihuahuan Desert was present in its current configuration (see Chapter 6.0). Little is known regarding the resource structure prior to that development, but it appears that at the close of the Pleistocene, woodland and grassland communities dominated the region. The Chihuahuan Desert scrub community is, conversely, characterized by xeric species such as mesquite, sotol, agave, yucca, and a variety of cacti.

Within the current research area, we have previously identified six broad ecological zones that, as a function primarily of effective moisture, provide broad contexts within which to consider subsistence patterns at both site and intrasite levels. A defining characteristic for each of these economic landscapes is the presence of water, both in terms of direct rainfall and indirect moisture (i.e., runoff and rivers). Water availability, in conjunction with temperatures, soil characteristics, and extant vegetation, determine soil moisture. Soil moisture impacts plant and animal production. Soil moisture in deserts, as a function of extremely high variation in rainfall and runoff, both through time and across space, result in both highly variable and unpredictable production.

As a function of this environmental variation, most vegetation in the lowland portion of the study area is composed of either stress-tolerant (e.g., succulents) or annual plants. The highlands are dominated by competitive plants (see Grime 1977:1169-1170). These plant communities have developed different strategies over long periods of time in relationship with their biotic and abiotic environments. Hard (1986:17-32) has argued that these diverse strategies differentially invest energy in the production of reproductive elements (i.e., seeds) and green leaves that are available to humans. That is, production in areas characterized by stress-tolerant and annual plants respond rapidly to moisture, and these "pulses" are primarily comprised of production that is directly of use to humans and herbivores (see Grime 1977; Noy-Meir 1973, 1974, 1981). Conversely, areas characterized by competitive strategies differentially invest in the growth of nonreproductive elements, such as supporting tree trunks and branches (see Grime 1977). This production is generally not available for human or herbivore consumption. This production comprises the economic landscape.

While individual species of plants and animals will respond to periods of water stress or abundance in different ways, production of fruits and seeds during periods of stress will be reduced in most species. This impacts the availability of

jackrabbits and cottontails (Daniels et al. 1993; Davis et al. 1975), as well as large mammals (see Eicher 1978; Leopold and Krausman 1991; Mello 1977:21-48; Howard et al. 1990:30-38).

The economic landscape identifies potential resources. However, not all resources within the economic landscape are necessarily used in subsistence. Thus, it is critical that research is conducted both to identify what resources are available and what resources are actually used. Many previous investigations of subsistence in the region rely heavily on ethnographic analogs, usually using plant and animal species used by groups such as the Mescalero Apache, or other groups located in arid settings, for a significant component of interpretation. While these data are important and can provide models for how the region may have been used, they are not our primary focus as they are unrelated to archeological data collection and analysis. They are an additional source of data regarding how an economic landscape may have been used, but they do not identify which resources were used. For example, mesquite is often described as an "important" resource in most summaries of subsistence in the region. However, mesquite pods or seeds are almost never recovered in flotation samples, and processing tools such as pestals, while present, are not a significant component of groundstone assemblages. In such situations, the archeological data are essentially ignored. Clearly, there are a variety of processes that can be envisioned that would not result in the recovery of significant amounts of mesquite in an archeological situation even when mesquite is a major resource. However, these contradictions provide a challenge to our methodologies.

Below, we provide a discussion of the strengths and weaknesses of a variety of biological and artifactual data that can be applied to subsistence studies in the region, and discuss some of the results of their application. This is followed by a discussion of our current understanding of several subsistence issues, including agricultural dependence across space and through time, and dependence on large game, small game, large seeds

and nuts, small seeds, and succulents. This discussion identifies specific research questions that are applicable to developing baseline data for subsistence research.

9.2 BIOLOGICAL DATA

This section provides a discussion of various biological data groups that have been, or are, relevant to subsistence studies in the study area. The strengths and weaknesses of each data group are discussed and a brief summary of major applications of these techniques in the study area is provided.

A variety of biological data groups are relevant to subsistence studies, for they minimally provide data on resources exploited in an archeological context. While, in terms of human subsistence, most biological data are best treated as presence/absence measures, some quantitative measures of diet are available for certain data groups. All biological data groups have the additional possibility of being radiocarbon dated. They can provide information on what items were exploited, when these items were exploited, and in several cases, measures of the relative contribution of various items to overall subsistence.

9.2.1 Coprolites

The analysis of macrobotanical material recovered from desiccated human feces provides the most direct line of evidence for reconstructing human diets as the recovered material had been directly ingested. In addition, studies by Watson (1974) suggest that a given coprolite represents two to four meals that were consumed over the last 20 to 26 hours. That is, this data group records diet at an extremely short-time scale that can be estimated. Coprolites provide specific information on subsistence.

The interpretation of coprolite data, however, are impacted by differential effect of digestion. That is, coprolite data consist of undigested material, and therefore, these samples underestimate the true diet. This is especially the case with the nonseed

component of the diet. Seeds are common in such samples, as a function of their hard outer covering. However, soft plant tissues, being more easily digested, are seldom recovered from coprolite samples (Minnis 1989).

Note also that coprolites are rare in any given region. They are generally recovered in dry cave or shelter settings, settings that may reflect a seasonal component of the diet. Coupled with the short time span represented by such samples, coprolite data probably only reflect a small portion of the overall subsistence base.

Finally, problems with quantification or results and standardization of extraction procedures should be considered in any interpretation of coprolite data. With sufficient sample size, coprolite data can be successfully used as ordinal data (see Minnis 1989), but presence/absence analysis may be more appropriate for most applications.

A literature search failed to recover any reference to coprolite analysis even though shelter and caves have been the focus of several excavations at Fort Bliss. In fact, no reference to coprolites could be found in the study area. Coprolites, then, are an unexploited data set in the lowlands, and if appropriate material can be collected, coprolite analysis should be a high-priority area of research.

9.2.2 Flotation

Flotation analysis, introduced in archeology in the late 1960s (Struever 1968), provides an additional source of data on the use of plant and small animal resources in archeological deposits. Like all biological data classes, flotation has the advantage of providing both information on the types of resources used, and through radiocarbon dating, a direct chronometric date on the timing of that use. The use of flotation in archeology has revolutionized subsistence research.

However, a variety of processes affect the recovery of plant remains from flotation analysis, as well as the use of these data for quantitative inferences regarding subsistence. Minimally, these processes

include: (1) the density of charred material in an archeological deposit; (2) the environmental conditions to which a deposit has been exposed; (3) characteristics of the seeds and plants; and (4) the recovery and analytical procedures used.

As nonarcheological elements can be introduced into a sample by disturbance and bioturbation, it is necessary to assume that only charred plant remains are of archeological significance. Surprisingly, however, little is known regarding the factors that result in the deposition of charred materials within an archeological deposit. Pearsall (1983) argues that the density of charred plant remains in an archeological deposit is related to the intensity of activities involving fire. If fire is common, the potential for the accidental inclusion of subsistence items into fires is increased. Sites that have activities not involving fire, then, should have low recovery rates. Also, sites with intensive occupations, measured as either large populations or long-term occupations, should have a higher frequency of recovery relative to short-term settings simply as a function of greater opportunity for the accidental inclusion of botanical material into thermal features. However, the relationship between the frequency of such accidents, and the actual importance of a given item in the overall subsistence, is unclear. Some items, such as those requiring extensive heat for processing (e.g., starchy seeds, corn) may be over represented while others which do not require extensive heat (e.g., prickly pear fruit) may be underrepresented.

Once subsistence remains are deposited, they are subject to a variety of environmental conditions that can essentially destroy all remains. Recovery of material appears to be highest in dry cave and rockshelter settings, or in protected contexts, such as when significant structural remains are present that may serve to lessen environmental impact (see Poppler and Hastorf 1988). Characteristics of subsistence remains must also play a role in this deterioration. Seeds, which are often protected by a hard outer shell, have a greater probability of surviving under harsh conditions. Conversely, soft tissue plants exposed to a similar range of environmental conditions, should deteriorate fairly

quickly and not remain for analysis. Thus, seeds will tend to be overrepresented in botanical remains recovered from flotation while soft tissues will be underrepresented.

Finally, a variety of problems exist regarding recovery procedures and conventions for analysis and presentation. Clearly, the amount of sediment collected from a feature impacts the probability of taxa being recovered, especially when low rates of original deposition are present. Increasingly, researchers are reporting the volume of samples collected, and standardization of results in terms of the amount of sediments collected should be a necessary procedure in all analysis.

Given these potential problems, presence-absence data is the most frequent interpretive level used in flotation analysis. Several researchers, however, have recently used a measure of taxa ubiquity as an indicator of relative importance. Generally, the proportion of all samples with a given plant taxa is used (Minnis 1985; Popper and Hastorf 1988). This procedure lessens the impact of variable preservation and recovery, and provides a data set that is amenable to rank-order statistical analysis.

Flotation has been extensively used in the study area over the last two decades, and a variety of cultivated and wild plant remains have been recovered. The cultivated remains include corn, common beans, tepary beans, and squash, though it appears that only corn is reported for pre-A.D. 1000 contexts (see Ford 1977; Wetterstrom 1978; O'Laughlin 1986). Noncultivated remains frequently include chenopodium, amaranth, and portulaca (see Holloway 1994a, 1994b; Dean 1994; Leach et al. 1995).

While there are several interesting exceptions, most flotation analyses have frequently resulted in low recovery of plant taxa. Most researchers have argued that the low recovery rates are, in part, a function of small flotation sample size, which is generally two liters, coupled with poor preservation of botanical material in the semiarid study area (e.g., Dean 1994; Holloway 1994a). This position is summarized by Minnis for the Ground-based

Free Electron Laser Technology Integration Experiment (GBFEL-TIE) testing and excavation project on White Sands Missile Range.

Based on previous studies in the area, it was expected that flotation samples from the mitigated sites in the GBFEL-TIE study area sites would have very low densities of archeological plant remains. For this reason, flotation samples larger than those usually employed in most other areas of the Southwest were taken, ranging from 0.25 to 143.5 liters of soil. In archeological deposits in the Southwest with better preservation of plant remains, samples as large as these are unnecessary and unusual. However, results of this analysis have demonstrated that a low density of preserved botanical material is present in the samples, making the collection of large samples a wise decision (Minnis 1991:387).

Minnis' comments regarding a "low density of preserved botanical material" is an understatement. In a recent study in which 79 2-liter samples were submitted for flotation analysis, only three had any charred seeds present and all charred material was at a very low frequency (Holloway 1994a; Dean 1994). Even with substantially larger samples, recovery rates do not seem to improve dramatically. The results from the GBFEL-TIE project, where samples in excess of 20 liters were commonly collected, produced recovery of charred seeds in only 8 of 67 samples (see Minnis and Toll 1991). Similarly, of 345 2-liter flotation samples reported by Whalen (1994) for the site of Turquoise Ridge, only 23% contained charred seeds, most of which were noncultivated. These included purslane, dropseed, mesquite, yucca, and a variety of cacti. There are, however, a variety of samples from sites that have produced extensive remains. Most of these are both later in time and located along the alluvial fans. Cummings (1989) see also Miller (1989) reports extremely high recovery rates of charred remains from post-A.D. 1000 sites on the east-facing slopes of the Franklin Mountain fans. O'Laughlin (1986) notes high

rates at the Meyer Pithouse Village site near the eastern edge of the basin. Brook (1966b), citing an unpublished report by Vermillion (1939), reports the recovery of approximately 200 bushels of charred corn from the excavation of a single pueblo room. Leach et al. (1995), in one of the few cases of high recovery from the central basin, reports the recovery of 50 charred chenopodium seeds from a single 2-liter sample from the floor of a structure. These studies suggest that, though uncommon, flotation results can yield critical data for subsistence studies in the study area.

Hard et al. (1995) have recently summarized flotation data for the lowland region with regard to the recovery of maize. Using a variety of sites from throughout the area, that summary suggests that maize is infrequent before A.D. 1000 even though it may be present in the region as early as 1000 B.C. (Tagg 1993; Upham et al. 1987). Maize was absent in 29 Archaic period samples. In over 500 flotation samples from the Mesilla phase, only 15 (3%) had any maize present. Conversely, of 82 samples from contexts after A.D. 1000, 33 (40%) had maize present. While this increase may certainly be related to preservation, settlement intensity, and possible locational shifts at A.D. 1000 (see Mauldin 1995), Hard et al. (1995) interpret the increase in maize ubiquity as indicative of an increased dependence on maize after A.D. 1000.

Flotation analysis in the study area, then, is frequently plagued by low recovery rates. The low recovery rates may be a function of environmental conditions, and clearly argue that samples larger than the standard 2-liter size should be routinely collected. However, the recovery rates, even with larger samples, may not be significantly improved. The extremely low recovery rates in the study area may also be related to the intensity of feature use. That is, these low rates may reflect a low intensity of occupation which would result in a decreased opportunity for charring of food remains. The low recovery rates may be a function of the nature of the occupation, in addition to problems of sample size and postdepositional impacts. Given the results of Hard et al. (1995), and the observation

that flotation recovery may reflect intensity of use, flotation samples should clearly continue to be a standard practice during all excavation and testing conducted in the region.

9.2.3 Pollen

Pollen analysis has primarily been used in environmental reconstruction, but also can provide data on subsistence. Pollen grains are produced by vascular plants during reproduction. Each species produces a morphologically dissimilar pollen that can be used fairly easily as an identifier to the family or genus level. Unfortunately, the interpretation of pollen frequencies from a location in terms of subsistence is hampered by a variety of factors, including inconsistencies in analytical conventions, destruction of pollen characteristics that allow the identification of grains to a family or genus level, and the development of linkages between the frequencies of a given pollen group and its relationship to human subsistence (see Bryant and Holloway 1983). The potential and problems associated with the use of pollen in subsistence studies is briefly summarized below.

Being associated with plant reproduction, pollen is extremely common in the environment. A variety of different pollen production rates and methods of dispersion occur. Wind pollinated plants produce the largest number of grains and are the most widely distributed. Conversely, plants that rely primarily on birds and insects for dispersion produce fewer grains and are generally not represented in a pollen analysis. Moore and Webb (1978) suggest that a single pine tree, which is wind pollinated and has lightweight grains, may produce several billion pollen grains. These can disperse over hundreds of miles. Maize is also wind pollinated but is composed of much larger pollen grains, therefore, maize pollen recovered from sediment is less likely to reflect long-distance wind transport. The variation in pollen production rates, and the fact that pollen is frequently transported by wind, complicates any simplistic association between the amount and type of grains recovered from archeological sediment, and the use of a plant in subsistence.

The preservation of pollen in a form allowing for relatively clear interpretation is another problem area, especially in arid or eroded situations. Pollen preservation is a function of a variety of factors, the most important of which seem to be mechanical and chemical weathering. Soil movement can cause significant and differential abrasion of pollen grains, selectively destroying recognizable characteristics (see Hall 1985). In addition, Holloway (1981; personal communication 1993) has argued that pollen grains can be destroyed by alternating cycles of moisture and drying, which may be associated with seasonal rainfall patterns. In addition to these mechanical factors, chemical destruction of pollen grains seems to be accelerated in settings with high alkaline soils, especially those with pH values higher than 6.0 (Bryant and Holloway 1983). While pollen can be recovered from these settings, they are often deteriorated to a point that an assemblage has little interpretive potential.

The final problem area in pollen interpretation seems to be associated with procedure for quantification. The most common approach is for an analyst to count a minimum number of pollen grains from a sample (usually less than 200), and use the percentages of grains in a given plant class to infer relative plant frequencies within that sample (Barkley 1934). Comparisons between samples then provides a mechanism for monitoring change through time or across space. However, as percentage calculations sum to 100%, a change in any pollen frequency causes changes in other taxa. Thus, significant directional changes can occur in a given taxa when no such change is actually present in that pollen class.

To overcome this problem, several researchers have used frequency calculations tied to concentration values generated from adding a known quantity of marker spores to a sample prior to processing (e.g., Holloway 1994a). The use of a known spore count permits the calculation of pollen concentration values and also functions as a measurer of accidental destruction of pollen grains during laboratory processing (Holloway 1994a). This procedure provides a more reliable estimate of

pollen frequencies as the analysis counts a minimum number of marker grains rather than a minimum number of fossil pollen grains.

While pollen analyses as a paleoenvironmental tool are frequent in the study area (Freeman 1972; Horowitz et al. 1981; Hall 1990b; Bradley 1983; Culley and Clarey 1980; Dean 1989; Cummings 1993), only a few studies have recovered pollen that can be directly related to subsistence (e.g., Holloway 1994a; 1994b). Holloway (1994a, 1994b) reports the successful isolation of a high frequency of cheno-am grains from a pollen wash on a metate recovered from a structure, and the recovery of maize pollen from a sample collected in the central basin. Also, Cummings (1989) reports the recovery of cheno-am pollen from a variety of features along the Franklin fans. While difficult to directly interpret in terms of subsistence, these studies suggest that pollen can provide presence/absence data for analysis.

Pollen studies for either paleoenvironmental or subsistence conducted in the study area are hampered by both low concentration values and the degraded nature of the pollen recovered. A high percentage of indeterminate pollen is characteristic of most studies. This may be a function of mechanical weathering (wet/dry cycles, sediment movement) and the generally high pH values (+7.8) of sediments in the study area (see Khresat 1993). Note that the collection of larger samples for analysis will not solve this problem (contra Horowitz et al. 1981). While the collection of larger samples will certainly produce more pollen for study, these samples will still have relatively high percentages of unidentifiable remains. Thus, the interpretation of the data are still based on a relatively small number of intact grains that are probably biased toward certain pollen types.

In spite of these problems, pollen washes on groundstone artifacts and the recovery of economically important pollen from sediments have been successfully conducted in the region. While the interpretive problems are substantial, pollen collection from archeological features in the

study area is a currently underused technique that may provide critical data for subsistence studies.

9.2.4 Phytoliths

Phytoliths, microscopic silica particles formed in and between cell walls by the deposition of silica absorbed from water, often have diagnostic shapes or sizes which are specific to a plant taxon (see Rovner 1983; Pearsall 1978; Bozart 1993). The outer silica wall is resistant to decay and phytoliths can be preserved over a significant period of time in most sediments.

At a general level, phytolith analysis is comparable to the analysis of pollen and the collection techniques are essentially the same. However, phytoliths from a given taxa can vary significantly in size and form as a function of the diverse places that they form. Consequently, in order to correctly identify a phytolith to a particular taxa, reference collections, specific for plants within a region, must be developed. Unlike most pollen, however, phytoliths decay in place and are redeposited into soil. That is, they are not significantly disturbed directly by wind, but soil movement may redeposit phytoliths into new contexts. In addition, phytoliths can exhibit movement down through a profile (see Buck 1993). While composed of silica, phytoliths can be dated using radiocarbon procedures as they frequently trap, within a silica shell, organic material applicable to AMS dating (Rovner 1983; Piperno 1988; Bozart 1993).

While primarily used for paleoenvironmental reconstruction, several researchers have used phytoliths in subsistence studies. These studies include the recovery of phytoliths from dental remains and the isolation of phytoliths from the edges of lithic tools (see Rovner 1983). Within the study area, however, the only studies of phytoliths thus far conducted are centered on paleoclimate research. Buck (1993) reports the successful recovery of phytoliths from both fan and basin samples in the study area and concludes that additional phytolith analysis may provide important paleoclimate data. Conversely, Cummings (1993) had low recovery of phytoliths and concludes that

additional studies are not recommended in the study area for paleoclimate research. Clearly, phytolith analysis is an unexplored technique, especially in subsistence studies. Despite potential problems, including low recovery rates and the lack of a comparative reference collection, phytolith analysis should be attempted in subsistence studies. In many ways, phytoliths are complementary to both pollen and macrobotanical analysis, and while not without problems, phytoliths have the potential to complement these more traditional studies.

9.2.5 Faunal Remains

The recovery and interpretation of faunal material from archeological sites provide a source of information on animal dependence in subsistence studies (see White 1953; Grayson 1984; Styles 1981). However, like all biological techniques, a linkage between the recovery of remains and reconstruction of the importance of a given species faces a number of complications. These include the elimination of remains not associated with subsistence, an assessment of the impact of environmental processes on the sample, and the development of quantitative measures for the importance of a given class of remains for subsistence.

Prior to the early 1980s, most faunal analysts used the minimum number of individuals (MNI) represented at a site, usually in combination with usable meat-weight estimates for an individual animal, to arrive at estimates of the importance of subsistence from faunal remains (see White 1953; Styles 1981). However, several recent critiques of MNI and meat-weight procedures (see Binford 1981; Grayson 1984), coupled with ethnographic studies of faunal transport decisions and costs (see O'Connell et al. 1990), have resulted in the frequent use of the number of identifiable specimens (NISP) of one of several meat utility indices. NISP values are the most commonly used measure, and when used in combination with MNI values, seem to provide a more easily interpretable and comparable measure of the importance of fauna in subsistence (see Grayson 1984).

Another increasingly recognized problem in faunal interpretation is associated with the recognition of remains that are unrelated to subsistence. These intrusive remains, which, in open sites, can include burrowing animals (e.g., horned lizards, rodent species) and in cave and shelter settings can include a variety of remains introduced by carnivores and raptors, complicate any simplistic use of faunal remains for subsistence. The presence of modification, including cut marks and burning, are important elements in identifying faunal material used for food. While not all animals are processed by cooking, and while faunal remains can become charred in a variety of ways not necessarily related to subsistence, the presence of burning or other modification is an expected identifier for subsistence items.

Finally, problems associated with both preservation and sampling must be considered in any evaluation of faunal data. Preservation bias, especially as it impacts specific elements or species, can alter the assemblage. Bone is susceptible to deterioration, especially under extreme environmental conditions, and can be further ravaged by carnivores. A variety of studies (see Binford and Bertrum 1977; Lyman 1984, 1993; Grayson 1989) have demonstrated that nonhuman factors, such as bone density and carnivore gnawing, can significantly impact what remains of a faunal assemblage at a location. In addition, several studies have consistently demonstrated that recovery, especially of smaller remains, is significantly impacted by choices of screen size. The recovery rates, and the species and elements represented, in that recovery are dramatically different in essentially the same contexts when 1/4-inch mesh is replaced with 1/8-inch mesh (see Schaffer 1992).

A variety of faunal remains have been recovered from prehistoric sites in the study area (e.g., Russel and Hard 1983), Bradley 1983; Stratton 1994; Dawson 1993; Whalen 1994). The faunal data from sites in the lowlands consistently suggest a focus on small and medium-sized mammals (see O'Laughlin 1979, 1994). While a number of species may have been used, including rodents, birds, and fish (see Bradley 1983; O'Laughlin

1979), much of the fauna recovered seems to suggest a focus on hares and rabbits. Large mammals (e.g., deer, antelope, mountain sheep) account for little of the recovered remains (see Dawson 1993), and small mammals other than cottontails are also of minimal importance once the probable intrusive taxa are eliminated (see Stratton 1994).

Faunal remains have been recovered from all major environmental zones, including the basin, fans, mountains, and along the river. Recovery seems to be highest at nonbasin sites and at sites with structural remains; occupations in the central basin, especially those without structures, have low recovery rates. Whalen (1994) reports a mean density of 31.5 g per cubic meter of fill (median = 24 g) at the architectural site of Turquoise Ridge, a sample of which was analyzed in detail. Eighty-eight percent of the sample were lagomorphs and no large mammals were recovered. Remains from several structures excavated at the Huesito site, located in the central basin, were also dominated by lagomorphs and had a median bone density of 724 g per cubic meter (Whalen 1994). Excavations at the Conejo Site along the east-facing slopes of the Organ Mountains recovered an astonishing number of jackrabbit and cottontail remains (see Russel and Hard 1983). Dawson (1993) reports on a variety of fauna from excavations at Todsens Cave in the Organ Mountains, including the recovery of mule deer and mountain sheep. Bradley (1983), excavating at the Pueblo period site of La Cabrana along the river, reports the recovery of over 5,000 fish bones and scales, most of which appear to be catfish and gar.

Within the central basin, a large percentage of many faunal assemblages, especially from those sites that lack structural remains, are characterized by a high frequency of fragments that can only be assigned to general size classes. For example, Stratton (1994), in a study of 1,176 faunal items from small sites in the central basin that had a high probability of reflecting prehistoric use, found that 931 (79%) were unidentifiable beyond a general mammalian size class (e.g., small mammal).

Mauldin, Leach and Monger (1994) suggest that one possible reason for the low recovery of identifiable faunal remains in the central basin may be related to deterioration. Using bone, which has a high probability of being associated with subsistence, they contrasted the median pit volume for a variety of features by the presence/absence of both burned bone and artifacts, and demonstrated that features with bone have a significantly greater volume. There is, however, no patterning in artifacts and feature volume. The lack of patterning in artifacts, which should not be destroyed by exposure, suggests that the greater recovery of bone in features with greater volume is a function of differential erosion and deterioration. While the rate at which exposed bone deteriorates in this environment is not known, once faunal material is exposed on the surface, deterioration may be quite rapid.

Faunal remains in the study area, then, have been recovered from all environmental zones. While the remains from a variety of animals are present, including large mammals, the assemblages are dominated by the remains of small and medium-sized mammals. Most of these small and medium-sized mammals appear to be lagomorphs. The assemblages, especially in the central basin zone, appear to be highly fragmentary, especially in those cases where structures are lacking. These assemblages appear to be highly deteriorated, probably as a function of exposure. As with the macrobotanical data summarized above, studies of environmental specific deterioration are critical if we are to successfully incorporate faunal material from sites and features within the study area most effectively into subsistence studies.

9.2.6 Isotope Signatures in Bone Collagen

The use of stable carbon and nitrogen isotopes to investigate diet in archeological research is a relatively recent technique (DeNiro 1987; DeNiro and Epstein 1978; Vogel and van der Merwe, 1977). While variation in nitrogen isotopes (N^{14}/N^{15}) have been used to study changing dependence on marine relative to terrestrial animals, the principal isotopic signature or interest

here is variation in carbon. Carbon isotopes analysis is based on the observation that plants incorporate carbon from the atmosphere using one of three photosynthetic pathways that result in distinct stable isotope ratios of carbon (Smith 1971, 1972; Bender et al. 1973). These isotopic signatures are then incorporated in the bone collagen of animals that eat those plants (DeNiro and Epstein 1978; DeNiro 1987). Most plants use the C3 or Calvin-Benson pathway to assimilate CO₂, which results in an isotopic value expressed in parts per thousand, of around -26.5 $\delta^{13}\text{C}$. Although there is considerable variation in the isotopic signatures of plants that use this pathway, there is no overlap between the carbon isotopic ratios produced by C3 plants and those of the other major plant pathway, the C4 or Hatch/Slack pathway. Plants that use a C4 pathway have more ^{13}C and thus are isotopically "heavier," with $\delta^{13}\text{C}$ values averaging around -12.5 part per thousand. That is, these C4 plants are enriched in ^{13}C relative to C3 plants. A third pathway, CAM, is characteristic of succulents and results in an isotopic signature that falls between, but can overlap with, the C3 and C4 values (Bender 1968, 1971; van der Merwe 1982; Farnsworth et al. 1985).

When animals eat plants, these isotopes are incorporated into their bone collagen, with an additional fractionation of between 2 and 5 parts per thousand. Bone collagen, then, is enriched in ^{13}C relative to the values for the plants in the diet (DeNiro and Epstein 1978; DeNiro 1987; van der Merwe 1982). An herbivore that subsists only on C3 plants (average of -26.5 $\delta^{13}\text{C}$ parts per thousand) would have a bone collagen value of around -21.5 $\delta^{13}\text{C}$, whereas an animal that subsisted only on C4 plants (average of -12.5 $\delta^{13}\text{C}$) would have a bone collagen value of about -7.5 $\delta^{13}\text{C}$.

While modeling the diets of herbivores is relatively straight forward, omnivore diets are more complicated as they incorporate both plants and animals in their diet. Different factors may control the collagen synthesis in animals who eat both plants and animals (see Krueger and Sullivan 1984;

Sillen et al. 1989; Bumstead 1984; Parkington 1987), and the precise factors governing the production of the $^{13}\text{C}/^{12}\text{C}$ ratios in human bone collagen are not well understood. In spite of these potential problems, the results of stable carbon isotope studies on human bone collagen that attempt to identify dependence on corn agriculture have been impressive, especially in areas like the eastern United States. Corn uses a C4 photosynthetic pathway and when incorporated into environments dominated by C3 plants, such as the eastern United States, radical increase in delta ^{13}C values in human collagen can be directly interpreted as evidence of increased dependence on corn (see Ambrose 1987; Boutton et al. 1984).

Although the technique of stable carbon isotope analysis has considerable promise in C3 environments, the use of the technique in semi-arid environments such as the study area is problematic. Plants that use the C4 and CAM photosynthetic pathways are common in such settings (see Teeri and Stowe 1976; Teeri 1988; Black 1973; Stowe and Terri 1978). Human dependence on these plants should result in less negative $\delta^{13}\text{C}$ values in bone collagen, even without any dependence on corn. Essentially the same $\delta^{13}\text{C}$ pattern, then, could result from either a dependence on maize or a dependence on other C4 and CAM plants and animals. Carbon isotope ratios in human bone from arid settings, then, may only yield an estimate of dependence on C4 and CAM foods.

MacNeish and Marino (1993) present the only isotopic analysis of carbon and nitrogen on human remains conducted in the region to date. While plagued by a number of interpretive problems, including the identification of piñon as a C4 plant when it uses a C3 pathway, MacNeish and Marino present results from burials that span the period between 2600 B.C. and historic period burials. Of specific concern are data from 11 burials from the prehistoric sequence. Their work demonstrates a significant change through time in the delta ^{13}C signatures, which indicate increased consumption of C4 plants through time with a significant jump associated with the pueblo period. MacNeish and Marino (1993) interpret these changes as being

solely related to increasing agricultural dependence. However, a variety of C4 plants, and animals which feed on C4 plants, are present in the local environment (see Hard et al. 1995, Katzenberg and Kelly 1991). Thus, all that can be concluded from this study is that a change in dependence on C4 based plants and animals was occurring during the time frame represented by these samples. Nevertheless, the ratio of C4/CAM foods to C3 foods is an important component of subsistence remains. When coupled with other data sets (e.g., flotation data, groundstone attributes), the isotopic signatures can provide critical data directly informative of both subsistence in general and agriculture in particular. This is especially critical as the carbon isotopic signature represents diet over a long time scale, perhaps over much of an individual's lifetime, therefore, they provide a critical measure of long-term subsistence change.

9.2.7 Residue Analysis

In an effort to expand our understanding of subsistence, several researchers have recently explored the utility of residue analysis on artifacts and feature sediments. A variety of different techniques, including immunological-based analysis (see Downs 1993; Lowenstine 1985; Loy 1993; Cattaneo et al. 1993; Newman and Julig 1989), lipid studies (Marchbanks 1989), and research into the recovery of DNA (Pena et al., 1993), have been attempted. The most common of these involves the use of immunological-based analysis, usually designed to detect and identify blood residue on stone tools (see Newman and Julig 1989; Cannon and Newman 1994). Researchers using immunological techniques have identified a variety of animal residues on stone tools, several of which are Paleoindian in age (see Amick 1994; Cannon and Newman 1994; Brush et al. 1994). The validity of immunological results on archeological samples is, however, questioned by several researchers (see Cattaneo et al. 1993; Eisele 1994; Gurfinkel and Franklin 1988; Hyland et al. 1990; Child and Pollard 1992; Smith and Wilson 1990).

Essentially, two different immunological techniques have been used in the study area. Downs (1993) has used a combination of microscopy and chemical test strips as a preliminary screening procedure. Suspected residue samples are then subjected to an immunological technique for species identification. Downs (1993) conducted a series of such tests on artifacts from MacNeish's excavations at Todsens cave. No evidence of blood residue was uncovered on any of the artifacts scanned from the Todsens Cave excavation.

The immunological technique of cross-over immunological electrofluoresces, or CIEP (see Newman and Julig 1989), has also been attempted in the study area. The CIEP technique involves the exposure of residues isolated from artifacts or feature sediments to a series of antisera developed for particular species (see Child and Pollard 1992; Eisele 1994). Amick (1991; 1994) was the first to employ residue analysis in the current study area. He submitted a number of Folsom points to a commercial laboratory that conducted CIEP analysis, and positive reactions were recorded to rabbit, bison, and bear. Following Amick's initial study, over 200 archeological samples, including groundstone, fire-cracked rock, chipped stone tools, ceramics, and feature sediment, have now been submitted for residue analysis using the CIEP technique (see Mauldin, Leach, and Amick 1995; Leach and Newman 1994). While positive reactions occur at low overall rates (less than 20%), a variety of plant and animal species have been identified that are not commonly represented in other subsistence remains. These include the identification of both Felidae (e.g., bobcat and mountain lion) and Canidae (e.g., dog, coyote, and fox). These have not been documented previously as subsistence items in the region.

Recently, however, a series of actualistic tests of the validity of the CIEP immunological technique to correctly identify modern residues have been conducted which suggest that significant problems still need to be overcome before this particular technique can be successfully applied (see Amick 1994; Mauldin, Leach, and Amick 1995). In the

most extensive of these, Mauldin, Leach, and Amick (1995) note that in only 17 of 31 chipped stone artifacts with blood of known animals submitted for CIEP identification technique were residues correctly and unambiguously identified at a family level. In four cases, the CIEP technique failed to identify any residue on the blood-coated artifact, and in three cases, the modern residues were incorrectly identified. These results suggest that any subsistence information based on immunological results should be viewed with caution (see also Leach and Mauldin 1995).

Clearly, additional research, especially involving more blind tests, is required before we discount immunological techniques in general, or the CIEP-based immunological analysis in particular. Note also that residue techniques based on other procedures (e.g., Marchbanks 1989) should be explored. Yet, both the low overall recovery rate of residue on archeological specimens and the disappointing results from the experimental research suggest that, at the present time, results from any extensive use of residue analysis should be avoided. Clearly, however, this is a developing field, and a variety of advances will no doubt occur over the next few years.

9.2.8 Summary

This section has provided an overview of strengths and weaknesses of several biological data groups that can be used in subsistence research in the study area. Each of the biological data groups outlined above, with the potential exception of blood residue analysis, are relevant to subsistence studies, for they minimally provide data on resources exploited in an archeological context. With the exception of coprolite and phytolith studies, all have been used in subsistence research in the region with varying degrees of success. Persistent problems of preservation, sampling, and interpretation exist with all data groups, and the above summaries suggest that these biases, especially those associated with preservation, may pattern with geomorphic zones.

9.3 ARTIFACTUAL DATA

This section provides a discussion of various artifactual groups that are relevant to subsistence studies in the study area. The strengths and weaknesses of each data group are discussed, and a brief summary of major applications of these techniques in the study area is provided.

Unlike biological data discussed in the previous section, artifactual data groups cannot be directly dated. Consequently, we are forced to either assume that technological or stylistic changes are an appropriate indicator of temporal change, or that some level of spatial association between a given artifact and a chronometric date provides a date on the artifact. As noted in Chapters 4.0 and 5.0, the assumptions underlying stylistic or technological change are interwoven with cultural history notions of why that change occurs. Furthermore, given the complex patterns of erosion and deposition (see Chapters 5.0 and 11.0), any association between a chronometric date and an artifact should be questioned, especially when detailed geomorphic observations of the relationships are not available. Nevertheless, these artifactual data groups are relevant to subsistence studies, for they provide information on assemblages used to extract and process subsistence resources. While chronological placement is problematic, changes in these data groups provide an additional source of information.

Here, we discuss four data groups that can provide information on subsistence. These include lithics, ceramics, feature types, and perishable remains. In each of these data sets, we focus on morphological variability, as an indication of intended use.

9.3.1 Lithics

Two general categories within this data group, groundstone and chipped stone, are discussed. Within each of these categories, we focus on tool morphology (e.g., small manos, pestals, and projectile points) and use (e.g., striation and edge damage). We assume that there is some relationship between the frequency of these various tools at a location during a given time frame and

the frequency of subsistence items processed using these tools. While tools used in processing are not necessarily deposited at the location of use, attention to tool-breakage patterns, especially those associated with use, and overall size attributes of lithic tools, which may condition transportability, should allow the identification of spatial and temporal patterns that implicate subsistence.

9.3.1.1 Groundstone

While a variety of groundstone tools categories can be distinguished (e.g., mauls and axes), three general categories, which are directly related to subsistence processing, are of concern here. These are: 1) mortars and pestles; 2) small "one-hand" manos and basin metates; and 3) larger "two-hand" manos and slab, trough, and through-trough metates. While each of these grinding sets can be used to process a variety of subsistence remains, ethnographic descriptions (see Mikkelsen 1985; Mauldin 1993b; Christenson 1987b; Hard 1986; Wright 1994) and studies of use-wear characteristics (see Lancaster 1983; Adams 1989) suggest that these morphological distinction correlate with processing of several general sets of resources.

Mortars/pestles appear to be designed and used for breaking hard-shelled nuts (e.g., walnuts and piñon) and for mashing moist seed pods and nuts (e.g., mesquite). A number of ethnographic descriptions are available of the use of this tool set (see Bell and Castetter 1937; Mikkelsen 1985; Kroeber 1925). Mortars can be fashioned out of rock, wood, or earth, and pestles can be fashioned out of either wood or stone; there may exist some relationship between pestle form and mortar characteristics (see Kroeber 1925). The archeological visibility of mortars made of either wood or earth, and pestles made of wood, is, of course, limited.

Within the current study area, several researchers have noted the presence of mortars and pestles. Lehmer (1948:32) notes such tools at the site of Los Tules, and a variety of mortars and pestles have been described in the Hueco region

(Cosgrove 1947; F. Almarez, personal communication, 1995). The only detailed study of the distribution of such tools in the current study area is reported by Carmichael (1981). He provides an overview of mortars and pestal in relationship to the potential processing of mesquite. Based on his Maneuver Area 3-8 survey (Carmichael 1986a), and a review of mortars and pestles from ethnographic and archeological sources, Carmichael suggests that many of the pestles in the local area are "...the narrow type associated with wooden mortars" (Carmichael 1981:61), therefore, he focuses his investigation on pestles. The 3-8 survey recorded a total of 70 pestles or pestle fragments, and two stone mortars. Thirty-six single-component sites had pestles. Based on the association, Carmichael (1981:61) suggests that pestles are most frequent on Mesilla phase sites (n=9) relative to other sites. Carmichael concludes that mesquite processing is, therefore, most common in the Mesilla phase, but is also well represented throughout the prehistoric sequence. With regard to spatial distribution, Carmichael (1981) notes that many of the pestles are located in the Central Basin and may be associated with playas.

While Carmichael's review is extremely useful, the conclusions that mesquite is an important resource may not be justified as the overall occurrence of pestles is extremely low. Less than one pestle was discovered for every 14 square km of survey area, and less than 1% of the sites recorded in Maneuver Area 3-8 have any pestles present. While mesquite may have also been processed with manos and metates, especially late in the season when the pods tend to be dry, the low overall frequency suggests that the question of mesquite dependence as indicated by pestle frequency remains unresolved.

A variety of researchers, especially within the last few decades, have argued that variation in attributes of manos and metates can be used as a gross measure of agricultural and nonagricultural processing rates and, by implication, overall dependence on these resource groups (see Adams 1988, 1989, 1993; Lancaster 1983; Martin and

Plog 1973:216-217; Martin and Rinaldo 1947:316; Mauldin 1993b; Plog 1974; Hard 1986, 1990; Hard et al. 1995; Mauldin and Leach 1994). Much of this research focuses on differences in mano/metate size attributes, either grinding surface area, or length and width used as a proxy for grinding surface area. As manos are frequently more common in both collections and in the archeological record, much of this research has focused on these groundstone tools.

The relationship between mano grinding area and processing of both agricultural and nonagricultural grain is supported both by ethnographic, archeological, and experimental data (see Horsfall 1987:340-347; Lancaster 1983:75-86; Bartlett 1933:27-29; Plog 1974:139-141; Hard 1990; Mauldin and Tomka 1988, 1989; Mauldin 1993b, 1995). Larger, "two-hand" manos and slab, trough, or through-trough metates seem to be associated with situations of high agricultural dependence (see Morris 1990; Schlanger 1991). Smaller "one-hand" manos, conversely, are involved in many tasks. While these tasks may include the processing of both wild foods and agricultural grains, situations in which agricultural grains are a significant portion of the diet are consistently dominated by larger mano/metate sets (e.g., Mikkelsen 1985; O'Connel et al. 1983:88-93; Wright 1994). While other factors, such as limits on raw material size (see Stone 1994), mobility levels (e.g., Calamia 1983; 1991), and alternative processing trajectories for agricultural grains (see Hard 1986; Weatherwax 1954; Christenson 1987b) complicate this relationship, the occurrence of different groundstone sets can provide data on processing of both agricultural and nonagricultural items. Consequently, the other two groundstone data sets considered here are small (one-hand) manos/basin metates and large (two-hand) manos and slab/trough/through-trough metates.

Within the current study area, several researchers have considered mano and metate attributes with most focusing on mano size attributes. Calamia (1983, 1991) provides temporal and spatial data on mano and metate size attributes, though he is primarily concerned with mobility levels rather

than subsistence. Hard (1986) provides background to the use of manos and metate size attributes as well as an overview of these data with regard to subsistence. Recently, however, two studies have synthesized spatial and temporal aspects of groundstone in the region. The first of these is provided by Mauldin (1995) in his examination of mano size attributes using collections from a series of spatial zones. While data provided by Mauldin is primarily limited to spatial variation, Hard et al. (1995), in a more general overview of groundstone, provides temporal data on mano size changes in the study area.

Mauldin (1995) uses area measurements on over 771 manos from a series of environmental zones to consider patterning in size attribute. His spatial zones combine several of our ecological-geomorphic zones. Mauldin's central basin zone encompasses both our central basin and central basin playa area. He combines our alluvial fan/runoff zone and the Rio Grande River area into a second spatial unit. Finally, his third zone, the Mountain area, focuses primarily on the Sacramento portions of the uplands. In addition, Mauldin (1995) uses both site and isolated data in his mano study.

Using mano area, Mauldin demonstrates that the mean grinding area of 410 manos collected from the central basin is only 86.6 cm², and just over 11% of the manos would be classified as "two hand." Using area estimates of 225 manos from the better-watered alluvial fan/Rio Grande River zone, he demonstrates that mano area is, on average, significantly larger (mean = 119 cm²), and almost a third of all manos (31.7%) are in the two-hand class. Finally, the 136 manos from the Sacramento Mountains, have an average area of 151.3 cm² and over 50% fall into the two-hand size range. These size differences are statistically significant, and in combination with the differences in the percentage of "two-hand" manos, may suggest that agricultural activities were concentrated outside of the central basin zone, primarily along the fans and river areas, and in the mountain settings. That is, the lack of larger

manos in the central basin reflected little corn processing in this area and a focus on wild resources. Agriculture seems to have occurred along the fan/river area and in the mountains. The effect of distance on groundstone material selection has not been demonstrated. A half-day to a days walk from the central Basin to the fans probably excludes logistical procurement, but not as an embedded strategy. More research is warranted into this issue.

These differences may not only reflect spatial differences in the importance of agriculture, but also temporal differences. Hard (1986, 1990), using mano lengths as a proxy for area, has argued that agriculture becomes increasingly important late in the archeological sequence. Hard et al. (1995), using mano area collected from both excavation and survey data, demonstrate that mano area increases dramatically from Archaic sites to late ceramic (post-A.D. 1000) sites. These patterns suggest that although agriculture is introduced into the region quite early (see Tagg 1993; Upham et al. 1987), it is only after A.D. 1000 that it contributes a significant component to the overall subsistence in the lowlands. Interestingly, it is after A.D. 1000 that settlement patterns are concentrated along the alluvial fans and river setting, which are areas of more consistent water availability.

9.3.1.2 Chipped Stone

While a variety of chipped-stone tool categories can be distinguished based on morphological attributes, a clear link between most commonly distinguished forms and specific subsistence attributes has not been established. Consequently, we focus on a single morphological category, projectile points, which have been linked to hunting, and only discuss other tool forms (e.g., retouched flakes, utilized flakes) at a general level. In addition, we focus on raw material characteristics, which have been linked to relative dependence on plants or animals.

Throughout this discussion, we assume that a given task, or set of tasks, places constraints on tool

morphology. A set of morphological attributes is assumed to provide an optimal solution to a task with changes in that morphology resulting in reduced efficiency. Yet, the gains in efficiency that result from an optimal solution are properly seen against other costs. These include as the cost of tool production, quarrying activities and tasks associated with the total activity (see Jobson 1986). Variations in tool morphology, then, should provide some insights into the specific subsistence activities.

While ethnographic data on the range of chipped stone tools are limited, experimental research (see Jones 1980; Jobson 1986) shows that tool size and edge attributes are important elements in tool performance. Larger tools are more easily manipulated, especially without hafting. In addition, edge angles affect performance in that certain angles, by virtue of their sharpness and durability, are well suited for some activities and inappropriate for others.

Raw materials are a major component of overall tool size, edge-angle characteristics, and the durability and sharpness of a tool. Nelson (1981; see also Kelly 1985; Goodman 1944), after a review of ethnographic sources, suggests that coarse-grained raw materials are, as a function of the material, resistant to damage during use. That is, coarse-grained raw materials produce edges that are durable. However, coarse-grained edges tend to be relatively dull. In contrast, cryptocrystalline materials can produce extremely sharp edges, but such edges tend to be quite brittle. Nelson (1981) suggests that, given these material characteristics, activities that are focused on plant processing, or the production of wood tools commonly used in plant processing should involve an extensive use of coarse-grained materials. In contrast, activities involving hunting, including butchering, should focus on cryptocrystalline materials.

Projectile points, frequently associated with various hunting activities (see Churchill 1993) or warfare, is one of the most intensively studied tool classes. While most investigations are concerned with the use of point forms as indicators of cultural

interaction or diachronic change, there has been little investigation with regard to subsistence. Christenson (1986, 1987a) provides an extensive review of projectile point attributes that may be relevant to functional, and by extension, subsistence considerations. Relying on experimental, ethnographic, and modern archery studies, Christenson outlines a number of variables (e.g., shoulder width, thickness, weight) that affect the wound size and penetration depth. These changes suggest different weaponry delivery systems and killing power (Christenson 1986) and may reflect changes in prey items.

Other tools, such as simple utilized flakes and retouched tools, have been described for use in a variety of diverse activities. However, both macro- and micro-use-wear studies have suggested that characteristics use-wear patterns may be indicative of processing materials of different hardness. While use-wear patterns are difficult to quantify and are dependent, to a substantial degree, on specific raw materials characteristics, use-wear studies may provide an additional indicator of macro-level changes in subsistence (see Keeley 1980; Shea 1992; Tringham et al. 1974).

Within the study area, projectile points have commonly been used in cultural chronology/culture history studies, but have not been extensively investigated with regard to subsistence. No detailed study of point attributes as they relate to weaponry or delivery systems could be located, and the practice of summarizing metric attributes at a type-level hinder detailed functional studies. However, two general temporal trends may be present in the projectile point data base. First, as in most regions in the Southwest, projectile points decrease in size through time. While specific studies of this are not available, it appears that later ceramic sites are dominated by small points, usually in the size range of less than 2.5 cm, and tend to have thin cross sections. In contrast, many of the earlier forms are larger than 3 cm in maximum length and tend to have thicker cross-sections.

Secondly, there may be changes in raw materials used, especially between the Archaic and Late Ceramic period. Archaic points, especially those from the Early and Middle Archaic periods, tend to be made of coarse-grained materials such as basalt and rhyolite. Conversely, late ceramic points are dominated by high-quality materials, including a dependence on obsidian. These diachronic changes, when considered in a functional framework, are usually seen as relating to changes in a decrease in the size of prey items and a reduction in mobility resulting in more use of locally available, small obsidian nodules. Basic research, however, has not been conducted to address these suggestions.

In general, the number of projectile points from controlled archeological contexts is not great, especially prior to the Late Ceramic period. Points have been recovered in large numbers from the extensive surveys conducted during the late 1970s and 1980s, but in low overall densities given the size of the region. For example, Carmichael (1986a) reports approximately 900 points from the MA 3-8 survey, which is an overall frequency of less than 1 point per square km. Collectors have been taking points from Fort Bliss sites for over 50 years, and this may have served to skew the numbers recorded archeologically in recent years. Nonetheless, recent excavation on Fort Bliss suggests this is not the case. Fewer than 45 projectile points were recovered from over 11,000 m² of excavation (Mauldin, Graves, and Bentley 1994). While there are notable exceptions at the regional level, especially in cave and shelter locations (see MacNeish 1993:155-156), projectile points in the desert portions of the Hueco Bolson do not appear to be common. In contrast, Kelley (1991) reports the recovery of over 3,000 projectile points from a single site (Robinson) in the Sacramento Mountains. Interestingly, the faunal material recovered from mountain sites, as well as the range of fauna potentially available, is dominated by large game. In contrast, the lowland fauna are dominated by small and medium-sized mammals. Summaries of fauna remains from the lowland suggest that large game, though

infrequent, appears to be more common on Late Ceramic sites.

The remaining morphological forms, consisting of other formal tools and utilized flakes, have not been extensively studied in the current study area. While raw material changes through time have been noted, these are usually tied to mobility changes rather than subsistence. No detailed use-wear studies have been conducted, though several macro-level investigations have produced results that suggest that additional investigation may be warranted.

Clearly, chipped-stone tools in the study area are an underutilized class of material that may be related to subsistence. Any clear interpretation of chipped stone tools are complicated by changes in mobility, the ambiguity associated with changes in projectile point forms, and a lack of detailed study of use-wear characteristics produced by local materials. However, changes in both raw materials and projectile points recovered from a site or landform during a given time, as well as changes through time, should be associated with changing dependence on plants, as well as changes in prey items.

9.3.2 Ceramics

Ceramics, frequently used in cooking and storage activities, reflect subsistence change (see Braun 1983; Nelson 1985). We assume that a given task, or set of tasks, places constraints on vessel morphology. Consequently, changes in ceramic vessel form, as well as engineering characteristics (e.g., vessel thickness and temper), may be related to subsistence change (see Braun 1983). Here, we focus on changes in vessel morphology, though changes in temper characteristics and vessel thickness may also be relevant to subsistence change.

Ethnographic studies (see Linton 1944; Longacre 1991) suggest that bowls are generally used as serving implements while jar vessel forms are more likely to be used for cooking or for storage. Jar forms, as they are used in preparation, are

directly relevant to subsistence change. Vessel opening determines vessel access, while storage vessels, especially those designed for liquids, may be characterized by small openings. Cooking vessels, in contrast, should have both larger openings and be designed to reduced spillage.

Major changes in subsistence, such as the shift to agriculture, should be reflected in changes in vessel morphology. For example, several authors have argued that corn is frequently processed by steeping and soaking, activities that can be effectively accomplished with necked jars. Thus, locations that depend on grain agriculture should be dominated by necked jars. In contrast, tecomates would be less effective for boiling or liquid storage as their inverted rims would increase spillage and they generally lack large openings for easy access to vessel contents. While they can certainly be used in cooking, it is less likely that they would be involved in preparations that involve extensive boiling.

Within the current study area, a variety of studies that have focused on ceramic vessel form have been conducted (see Miller 1989; Scarborough 1986, 1992; Michalik and Batcho 1988; Whalen 1981b; Seaman and Mills 1988). Frequently hampered by small sherd size, a low frequency of rim sherds, and highly eroded body sherds, many researchers have focused on primary distinctions between bowls and jars rather than focusing on jar forms. Several researchers have identified somewhat greater proportions of bowls, which may be associated with serving activities, on large sites located along the margins of the central bolson. Scarborough (1986, 1992) reports that on 52 rim sherds from Meyer Pithouse Village, bowls comprise 48% of the assemblage. Miller (1989) reports that on Gobenador, a large site with several substantial pithouses, bowls make up 39% of the rim sherds. At the Conejo site located along the Organ Fans, Hard (n.d.) reports that 39% of 95 rim sherds are bowls. Conversely, several studies of the central basin suggest lower bowl frequencies. Michalik and Batcho (1988) report that bowls generally comprise less than 10% of the ceramic assemblage on several small sites in the central

basin. Mauldin, Graves, and Bentley (1994) report a similar percentage for jar sherds in the central basin. While details of jar vessel forms are lacking, these patterns may suggest that different processing requirements may be implicated at a landform level.

Changing frequencies of jar forms are of primary interest with regards to subsistence. In one of the more extensive studies of vessel form, Hard (n.d.) has compared variation in rim sherds from the late Mesilla phase sites of Conejo, located on the Organ alluvial fans, and 3:739 (Huecosito), located in the central basin zone. Hard's analysis suggests a complete lack of necked jars at Huecosito, and necked jars made up about 25% of the assemblage at the Conejo site. Hard (n.d.) concludes that these differences support a greater cooking/boiling frequency at the Conejo site, consistent with his suggestions that agriculture may be an important component of subsistence at this site. Scarborough (1986) reports a similar percentage of necked jars at the Meyer Pithouse village, where flotation data suggest a high frequency of domesticates.

Changing ceramic vessel forms, especially within the jar category, provide clues to subsistence as they may imply different levels of boiling/steeping that suggests general subsistence change. While a variety of other factors (e.g., changes in mobility) complicate this pattern, both the presence of ceramics, and changes in vessel form, should be reflecting major changes in subsistence.

9.3.3 Features

As with previous data groups, the primary concern here is with morphological variation that may be related to subsistence. While a variety of nonstructural features can be distinguished based on cross-sectional feature shape, size, and depth, we focus on two primary types: thermal features which have rock (e.g., caliche, rhyolite) present, and nonthermal features with undercut or straight sides. Thermal features that lack rock could be conceived as a separate category. However, the variability described within the study area in planview shape, cross-sectional shape, size, and

depth, along with descriptions from ethnographic sources, suggest that a variety of functions are probably represented in these nonrock thermal features, many of which are not related to subsistence.

In contrast to general heating functions attributed to nonrock thermal features, the addition of rock may be related to processing requirements associated with certain plant types. Ethnographic accounts of succulent processing (see Castetter and Opler 1936; Bell and Castetter 1941; Basehart 1974; Castetter et al. 1938) involve the use of "pit-baking." While details vary, this appears to involve the use of rock in relatively large, deep, earth-covered ovens. The presence of such features may, then, be one indicator of the use of these subsistence items.

The second feature type, consisting of straight or under-cut walls, may be related to storage. Ethnographic descriptions of the use of such pits are common (see DeBoer 1988). While a variety of storage options, including above-ground storage in baskets or ceramic vessels as well as in storage rooms are available, a common storage solution, especially where soil moisture is not a problem, involves below-ground storage (DeBoer 1988; Gilman 1983). While additional data groups are necessary to clarify what specific items are stored, the presence of such features implicate subsistence strategies.

Within the current study area, features, especially those which have either burnt caliche or other rock (e.g., limestone, rhyolite) are extremely common. Leach (1994) reports the presence of 1,273 features observed during surface collection of 14 square km near the Hueco Mountains, a density of over 90 features per km. The majority of these (n=894) contained fire-cracked rock (FCR), burnt caliche (BC), or a combination of both (Leach 1994). Mauldin, Graves, and Bentley (1994), working in the central basin, report a density of well over 200 features per square km. Using these density estimates, there are between 400,000 and 1 million features within the 4,500 square km area

encompassed by Fort Bliss. In short, there are a lot of features on the military reservation.

A variety of researchers in the local area, relying primarily on ethnographic descriptions from the Southwest, and to a lesser extent, archeological patterns in the local area, have argued that features with rock are designed to process succulents. Several authors have distinguished between large rock features, generally greater than 1 m, and small rock features, frequently less than 1 m in maximum size (see O'Laughlin 1980; Greer 1968; Whalen 1977, 1978; Hard 1983b). The implication of this distinction is that these two feature sizes may reflect different functions. However, O'Laughlin (1980), again relying on ethnographic sources, suggests that both are primarily used for succulent baking, with the primary distinction reflecting quantity of material processed rather than any difference in the items processed.

Mauldin, Graves, and Bentley (1994; see also Duncan and Doleman 1991) have conducted a variety of experimental studies with heat retention in rock that further elucidates the use of rock. Using temperature probes in experimental features with and without rock, they demonstrate a consistently higher temperature in rock features. In addition, the features with rock seem to retain the heat of the fire for a longer period of time. After nine hours, the features with caliche have an average temperature of over 300°C, which is twice that of the feature that lacked stone. This research suggests that the function of rock seems to be heat retention over long period of time. If these features are used for cooking, then long-term temperature advantages probably relate to processing resources that have high starch content, such as agave and sotol, as these plant types are associated with the introduction of the Chihuahuan Desert vegetation pattern.

Leach (1993) has summarized extant data on FCR/BC features from throughout the Jornada Area. Using over 80 features with data on rock weight and associated radiocarbon dates, Leach demonstrates that while the vast majority of features with rock are less than 1 m in maximum

pit diameter and have total rock weights of less than 10 kg, a small number of cases have rock weight well in excess of 50 kg and are well in excess of 1 m. In several cases, weights in excess of 100 kg of rock have been recorded. Those cases in the high weight and size category are consistently located along the alluvial fans and consistently date after 1350 BP (Leach 1993). No basin FCR feature with rock weights in the plus 50 kg group exists in Leach's database. Interestingly, the distribution of sotol and agave, likely candidates for pit-baking activities, is currently limited to the alluvial fan zone. While additional work is clearly necessary, the dramatic increase in size and weight of features located in settings that have a high probability of containing agave and sotol, in conjunction with experimental and ethnographic evidence, suggests that the larger features may be associated with the processing of these items.

The second feature type, which may be involved in storage, has not been extensively investigated in the region. Wiseman (1991) uncovered several such features at the Bent site, located to the north of Fort Bliss in Otero County, and Kelley (1984) reports several bell-shaped pits from the Sacramento area. O'Laughlin's recent work at the Fire Cracker Pueblo, located along the eastern fans of the Franklin Mountains, has uncovered numerous such pits (O'Laughlin, personal communication 1994). In addition, Whalen has examples from his work at both Turquoise Ridge and Huecosito. Such pits, if in fact a storage function can be confirmed, clearly implicate subsistence.

Features comprised of both FCR/BC and those with possible storage functions provide important data on subsistence processing and, potentially, strategies. Unlike most of the artifact classes discussed above, these types of features are not mobile, and thus the occurrence at a site can be directly interpreted. FCR/BC may be involved with processing of plants, such as sotol and agave, and possibly yucca. While additional research is clearly required to explore this question, FCR/BC features may be some indication of dependence on

these plant sources. Storage features, especially if through phytolith and pollen analysis the material stored can be identified, are an additional source of dietary information and may provide important data on subsistence organization.

9.3.4 Perishable Remains

Information on the perishable component of subsistence technology is extremely limited as a function of preservation. Only in a few cases and in a single environmental zone (mountains or uplands) are data available. Thus, it is highly likely that any picture provided by such data are skewed. Nevertheless, ethnographic studies of both hunter-gathers and agriculturalists (see Pennington 1962; Steward 1938) suggest that wood and fiber components of subsistence technology is a critical element in both subsistence acquisition and processing.

Within the study area, a variety of excavations and collections of cultural material from cave sites in the Huecos and Sacramentos (see Cosgrove 1947; O'Laughlin 1977b; HSR 1973; Almarez, personal communication) provide the most detailed information on this component available. These investigations recovered a variety of items, including reed arrows and arrow foreshafts, a complete atlatl, a variety of basketry fragments, fiber and cotton cordage and netting, and throwing sticks. While of limited utility for the investigation of non-cave/shelter sites, these data provide a glimpse into the complex acquisition and processing technology represented by wood and fiber component of the subsistence technology. Clearly, additional work in these settings is needed, including detailed excavation, dating of these deposits, and a systematic inventory of these technologies.

9.4 RESEARCH QUESTIONS

A coordinated investigation into subsistence involves answering a variety of questions including identifying what resources were used, what the level of dependence on a given resource was, where resources were acquired, how and where

those resources were processed, what temporal changes were present, and why those changes occurred. As noted in the introduction to this chapter, the primary concern in this investigation of subsistence is with documenting actual resource use at a location and, in combination with chronometric dates, consider changes in that use through time. It is necessary to answer this question before we can proceed to the higher level questions of change. However, it is critical that, as research on the nature of subsistence is conducted, higher level questions are kept in mind. The previous two sections (9.2 and 9.3) have provided an overview of biological and artifactual data groups that may be usefully considered in identifying resources used for subsistence in the region. Each of these data groups have strengths and weaknesses, therefore, the most effective way to proceed involves the consideration of a variety of different data groups in combination.

Below, a variety of questions are identified for specific synchronic landforms and major changes in the resource landscape. In addition to natural changes through time in available resources, subsistence resource questions that are potentially associated with agriculture are also identified.

9.4.1 Synchronic Research

Synchronic research questions are focused on developing descriptions of the actual resources used as represented on sites in various landscape zones. Currently, potentially available resources include a variety of succulent (e.g., agave, sotol, yucca, cacti), large seeds (e.g., mesquite), small seeds and shrubs (e.g., drop seed, amaranth, chenopodium), large mammals (e.g., deer, antelope), small and medium-sized mammals (e.g., cottontails, jackrabbits, rodents) and a variety of other resources (e.g., birds, fish). In addition to these natural resources, agricultural resources appeared in the region around 3000 BP. These natural resources, as well as the viability of agriculture, change in distribution and density, in part as a function of soil characteristics and moisture that varies with landforms (see Satterwhite and Ehlen 1980, 1982; Bradley 1983;

Mauldin 1995). A number of general summaries regarding the distribution and periods of availability for specific noncultivated plants and animals are available (see Bradley 1983; O'Laughlin 1980; Mauldin 1995; Hard 1986), though they tend to be based exclusively on modern distributions. Progress in documenting subsistence in the synchronic realm is, in part, dependent on progress in paleoenvironmental reconstruction. Mapping those resources potentially available within a zone (the economic landscape) and documenting changes in that economic landscape provides the background data for comparing resources at a site with what resources are available within that zone.

Once a detailed understanding of resources is available, it is then possible, using methodological tools outlined above in Sections 9.2 and 9.3, to investigate synchronic subsistence patterns. For example, if charred fish remains were identified in archeological features in the central basin we could suggest that they have a high probability of being related to subsistence and also that they are not derived from that zone. While comparisons of subsistence remains to naturally available resources can be especially important for elucidating higher-level strategies (e.g., mobility, interaction), they complicate any interpretation of resources at the synchronic level. That is, the presence of resources or artifacts associated with processing those resources on a site within a given zone does not necessarily mean that those resources were acquired from that zone. The relationship between the recovery of resources at a location and the location of acquisition, production, processing, and consumption is closely linked to higher-level questions of strategy of resource acquisition, land use, and mobility strategies. For synchronic description, then, the more indicators of the use of a given resource type (e.g., corn kernels, maize phytoliths, maize pollen, two-hand manos/trough metates, necked jars, storage features) on a site or series of sites within a zone, the better the potential that the resource is produced and processed in that zone. Efforts should be made, then, to collect as many different data types from archeological settings as possible for any given resource.

General data needs for synchronic research are similar regardless of the zone. For a given archeological feature or structure, site-level deposits are required. At the scale of a landform, every effort should be made to collect the biological and artifactual data discussed in Sections 9.2 and 9.3. In addition, background research on paleoenvironmental patterns, chronometric dates, and technological aspects related to processing of subsistence resources must be conducted.

9.4.1.1 Central Basin Playa Zone

The landform unit consists of playas that dot the central basin and a radius, arbitrarily set at 1 mile, which surrounds those playas. As note in Section 8.4, the one-mile radius is an arbitrary and conservative approximation of the peripheral resource exploitation zone commonly used by mobile societies around a tethered resource such as a playa. The one-mile radius represents a 20 minute foraging pattern and will include most of any special purpose sites which may be functionally linked to the playa. The Central Basin Playa zone roughly corresponds to the Basin-Playa zone (see Hard and Mauldin 1986). The playas in this zone, several of which have been observed to occasionally hold water on a short time scale after intensive summer rains, potentially have a higher density of plant and animal resources relative to the remaining portion of the central basin. This zone may provide opportunities for the collection of a variety of plants and animals. The principal resources available in this zone appear to have been small and medium-sized mammals, some grasses, and mesquite. The following general resource questions should be investigated.

- 9-1 What are the natural plant resources actually used in subsistence at sites in this zone?
- 9-2 What are the animal resources actually used in subsistence at sites in this zone?
- 9-3 Are these noncultivated plant and animal resources represented in the subsistence base available in this zone?

- 9-4 Is agriculture a subsistence strategy used in this zone? What is the level of dependence on the various subsistence resources at any given point in this zone?

9.4.1.2 Basin Floor

This landform unit consists of the remaining portion of the central Hueco Bolson not encompassed in the playa zone. The central basin is currently dominated by mesquite-stabilized sand dunes, interdunal blowouts, sheet sands, and sparse vegetation. Much of the erosion appears to have occurred over the last 200 years. No permanent water resources are available in this zone and all plant production is a function of rainfall, which is highly variable across space and in time. Resources in this zone occur, therefore, at both a low density and with a low degree of predictability. The principal resources available in this zone appear to be small and medium-sized mammals and mesquite. Within this zone, the following general resource questions should be investigated.

- 9-5 What are the natural plant resources actually used in subsistence at sites in this zone?
- 9-6 What are the animal resources actually used in subsistence at sites in this zone?
- 9-7 Are these noncultivated plant and animal resources represented in the subsistence base available in this zone?
- 9-8 Is agriculture a subsistence strategy used in this zone?
- 9-9 What is the level of dependence on the various subsistence resources at any given point in this zone?

9.4.1.3 Alluvial Fans

This landform zone consists of the alluvial fans associated with the mountain uplands. This zone is an approximate 5-mile strip encompassing

several large playas at the base of the fans (e.g., Coe Lake, Stewart Lake). This zone corresponds to the "runoff" zone defined by Whalen (1977, 1978) as the distal ends of the fans receive runoff from the mountain uplands. This runoff can be substantial and will occasionally result in ponding water in the larger playas. For example, in 1984, as a result of a series of localized, intensive storms, standing water was observed for over seven months at the Coe Lake playa. The combination of runoff, rainfall, and soil characteristics of the alluvial fan zone results in the production of a variety of plant and animal resources. More importantly, these resources appear to occur at a relatively high density and are available on a more consistent basis. The principal resources in this zone include a high density of agave and sotol, as well as yucca and a variety of mammals, including deer at low densities during certain seasons. The following general resource questions should be investigated.

- 9-10 What are the natural plant resources actually used in subsistence at sites in this zone?
- 9-11 What are the animal resources actually used in subsistence at sites in this zone?
- 9-12 Are these noncultivated plant and animal resources represented in the subsistence base available in this zone?
- 9-13 Is agriculture a subsistence strategy used in this zone?
- 9-14 What is the level of dependence on the various subsistence resources at any given point in this zone?

9.4.1.4 Otero Mesa

This landform consists of the upland mesa along the northwestern edge of Fort Bliss on the McGregor Range. In contrast to other landforms, relatively less is known about the archeological patterns within the Otero Mesa zone. A sample survey and some limited testing was conducted in

the 1970s (Beckes et al. 1977) and more recently, extensive survey has been conducted in preparation of the Roving Sands exercise (Jim Bowman, personal communication). The resource structure is also relatively unknown. Currently, this unit is dominated by relatively stable grasslands with a variety of cacti and other succulents present. A variety of faunal resources have been observed in this region, including several small herds of antelope and the occasional deer. Beyond acquiring baseline data on the ecological and archeological resources present on Otero Mesa, the following general resource questions should be investigated.

9-15 What are the natural plant resources actually used in subsistence at sites in this zone?

9-16 What are the animal resources actually used in subsistence at sites in this zone?

9-17 Are these noncultivated plant and animal resources represented in the subsistence base available in this zone?

9-18 Is agriculture a subsistence strategy used in this zone? What is the level of dependence on the various subsistence resources at any given point in this zone?

9.4.1.5 Uplands

This landform unit consists of the bedrock uplands, including the nonalluvial portions of the Organ, Franklin, Hueco, and Sacramento mountains. Resources vary, primarily as a function of temperature and precipitation associated with higher elevations, and there is data to suggest that the uplands, in some sense, have a complementary structure of resources relative to the lowlands (see Hard 1986; Mauldin 1995). Major resources in this zone have included large mammals (e.g., deer, elk, bison) and nut resources (e.g., piñon). The following general resource questions should be investigated.

9-19 What are the natural plant resources actually used in subsistence at sites in this zone?

9-20 What are the animal resources actually used in subsistence at sites in this zone?

9-21 Are these noncultivated plant and animal resources represented in the subsistence base available in this zone?

9-22 Is agriculture a subsistence strategy used in this zone?

9-23 What is the level of dependence on the various subsistence resources at any given point in this zone?

9.4.1.6 Riverine Zone

This landform unit consists of the Rio Grande River and associated floodplains and terraces. While not represented on Fort Bliss, the zone provides a variety of resources that are not available in any other zone. These include a variety of riparian plants and animals, including fish. As this landform is not present on the post we must rely on regional investigators to provide data relevant to the following questions.

9-24 What are the natural plant resources actually used in subsistence at sites in this zone?

9-25 What are the animal resources actually used in subsistence at sites in this zone?

9-26 Are these noncultivated plant and animal resources represented in the subsistence base available in this zone?

9-27 Is agriculture a subsistence strategy used in this zone?

9-28 What aquatic resources are used?

- 9-29 What is the level of dependence on the various subsistence resources at any given point in this zone?

9.4.2 Diachronic Research Issues

In addition to the investigation of synchronic issues, a variety of diachronic subsistence issues must be investigated. The primary concern involves documenting changes in the overall subsistence base through time. The question of spatial scale- regional (Jornada), subregional (lowlands), zonal (e.g., alluvial fans, central basin), site, and intrasite levels are applicable to all questions, provided that the necessary data can be acquired. The general data needs for investigating diachronic research issues are similar to those for synchronic issues noted above; details are outlined in previous sections. However, specific data requirements can be identified and are summarized after each section below. As with the synchronic investigations, background research on paleoenvironmental patterns, chronometric dates, and technological aspects related to processing of subsistence resources must be conducted.

The structure of the research questions are guided by a theoretical perspective briefly outlined at the beginning of this chapter. Consequently, we focus on changes in the natural environment, potentially brought about by climatic change and human use of the region, to structure the investigation. However, the principal concern here is with a description of changes through time rather than with explanations for that change. While the two realms are certainly related, a variety of explanations, both from a cultural/ecological perspective as well as from other perspectives, can be applied to the same description.

9.4.2.1 Diachronic Trends in Natural Resource Use

Given the cultural/ecological focus of this research design and the observation that changes in the economic landscape should result in changes in the subsistence structure, it is appropriate to structure investigation into diachronic change on the basis of

major changes in the economic landscape. While a variety of temporal scales of change can be investigated (see Mauldin 1995), recent research has clearly indicated that the major change in the economic landscape within the region is associated with the introduction of the Chihuahuan Desert (see Monger 1993a; VanDevender 1990; see Chapter 6.0). Thus, it is appropriate to investigate the pre-Chihuahuan Desert subsistence regimes separate from the post-Chihuahuan Desert subsistence regimes.

Little is known regarding the resource structure prior to that development, but it appears that at the close of the Pleistocene, woodland and grassland communities dominated the region. The Chihuahuan Desert scrub community is, conversely, characterized by xeric species such as mesquite, sotol, agave, yucca, and a variety of cacti. The development of the Chihuahuan Desert, then, introduced an entirely different suit of resources, many of which (e.g, agave) have specific processing requirements. The exploitation of this new economic landscape should be considerably different than that reflected in the pre-Chihuahuan ecological setting.

For both the pre-Chihuahuan Desert period, and the post-Chihuahuan Desert period, the following research questions should be investigated.

- 9-30 What is the pattern of dependence through time on C3 vs. C4 and CAM plants?
- 9-31 What is the pattern of dependence through time on small/medium-sized faunal resources?
- 9-32 What is the pattern of dependence through time on large mammals in the region?
- 9-33 What is the pattern of dependence through time on other resources (birds, fish)?

9-34 What is the significance of these patterns?

Data requirements can be identified for the general subsistence classes. For floral resources, these include the presence and characteristics of rock features, lithic use wear patterns, lithic raw material patterns, pestles, small manos and basin metates, macrobotanical samples, pollen and phytolith samples, and ceramic vessel forms. For animal resources, data requirements include faunal, projectile morphology, raw materials, lithic use wear, nets, snares, clubs, and possibly residue analysis.

9.4.2.2 Changing Agricultural Dependence through Time

As noted previously, agriculture is first present in the region at around 3000 BP, based on direct dates on corn from the Organ (Upham et al. 1987) and Sacramento (Tagg 1993) mountains. However, the level of dependence remains unknown. Ceramics, which are commonly associated with high levels of agricultural dependence, do not appear until around 1750 BP. As summarized above, currently available flotation data suggest that agricultural remains are not commonly in flotation samples until after A.D. 1000. Changes in groundstone suggest a similar pattern with larger groundstone comprising a significant portion of groundstone in the region after A.D. 1000. Finally, carbon isotope data also suggest a jump in dependence on C4 plants, which would include maize, late in the prehistoric sequence. Figure 36 contrasts these various indicators for the lowland portions of the study area. All clearly suggest that the pre-A.D. 1000 pattern is one of limited dependence on agriculture. The period between 3000 BP, when agriculture was first introduced to the area, and the 1000 BP, when agriculture appeared to be a major component of subsistence, is of considerable interest. The degree to which agriculture was actually practiced in the lowlands prior to A.D. 1000, what level of dependence agriculture represents during this period, and what brought

about the increased dependence suggested after A.D. 1000 (see Figure 36) remains unclear.

Because agricultural strategies are closely related to so many other components of a cultural system (including mobility, occupational intensity, overall land use, and technology) which are not directly covered in this chapter, documenting agricultural levels is a primary concern. The following research questions should be addressed.

9-35 What is the pattern of dependence on C3 vs. C4 and CAM plants?

9-36 What is the overall level of agricultural dependence in the region through time?

9-37 When does agriculture become a resource produced in the lowland portion of the study area?

9-38 What is the level of dependence in the lowland portion of the study area?

9-39 How does the changing level of agriculture articulate with changes in other resources?

9-40 What changes in settlement patterns occur contemporaneous with the development of agriculture?

9-41 What changes in social organization occur contemporaneous with the development of agriculture?

9-42 What changes in human population biology occur contemporaneous with the development of agriculture?

Data requirements for effectively considering these questions involve the collection of ethnobotanical samples, groundstone information, phytolith and pollen samples, data on ceramic presence and vessel form, data on possible storage features, isotope and epidemiological analysis of burials, lithic use-wear and raw materials used, and coprolite information.

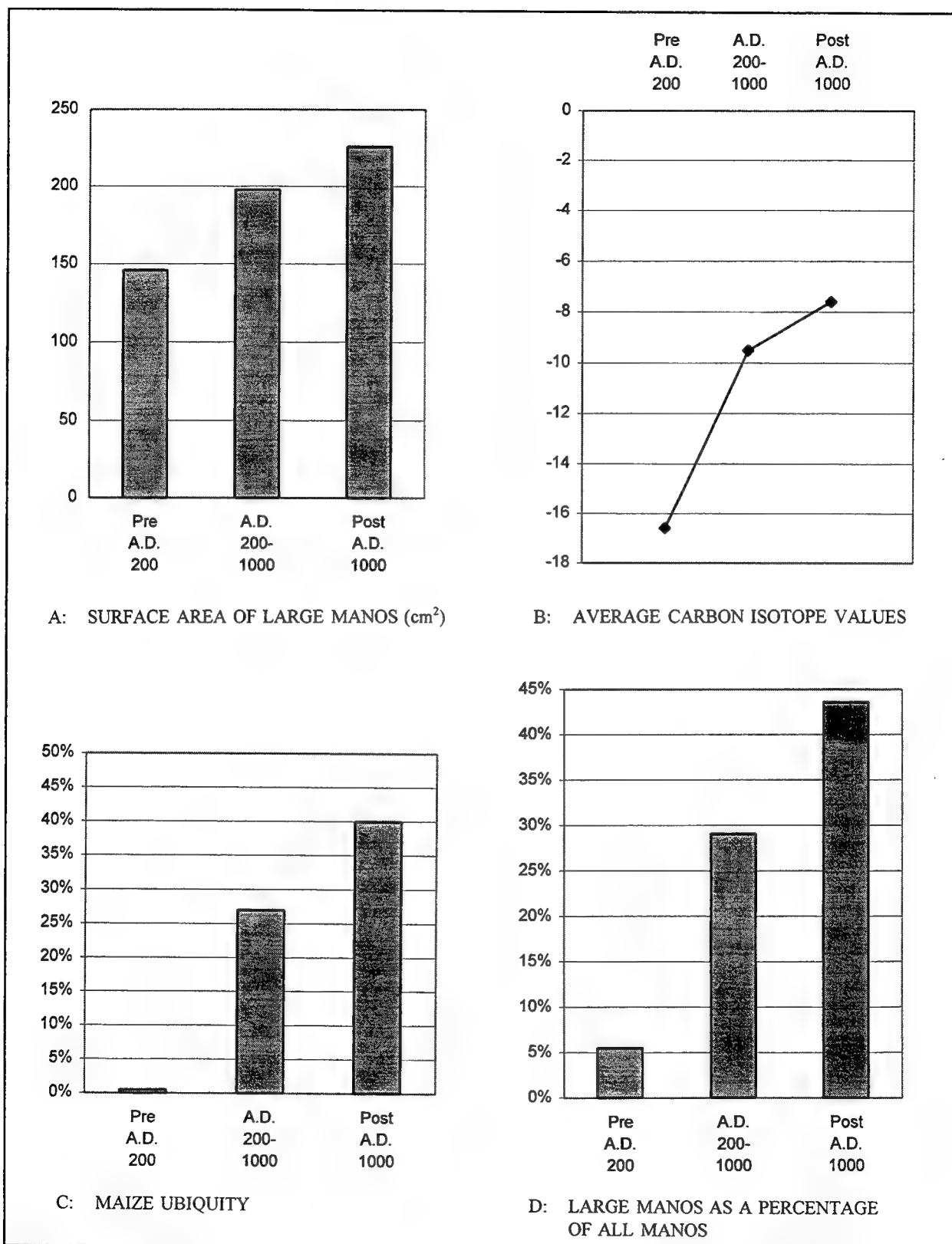


Figure 36 Changes Over Time in Selected Agricultural Indicators Within Lowland Portions of the Study Area.

9.5 SUMMARY

Subsistence decisions comprise a critical element in human adaptations, impacting technology, settlement strategies, mobility levels, seasonality, and the overall cultural organization. Investigating and explaining subsistence organization involves: (1) the identification of resources used at various times and places within the region; (2) developing a description of the mobility and technological strategies used to acquire those resources; (3) documenting changes through time and across space in those mobility and technological strategies; and (4) developing explanations for those changes. We have focused on methods that may be relevant to answering the first of these questions, documenting what resources were involved in subsistence at various times and places. In addition, specific research questions, involving both differences in space and through time, have been presented. Clearly, this represents an initial step, and the higher-level questions of changes in mobility and organization must be investigated once the initial patterns have been defined. Of course, progress in this research area involves progress in the chronometric, paleoenvironmental, and technological research realms.

10.0 CULTURAL INTERACTION RESEARCH DOMAIN

*Robert J. Hard, Patience E. Patterson, and
Cynthia L. Tennis*

The role of cultural interactions in the process of social change is enormously complex and has been a major focus of anthropological, sociological, and geographical research for most of this century. However, for the purposes of investigating Fort Bliss archeology, cultural interaction can be subdivided into three key issues.

- 1) What kinds of cultural interaction occurred involving the inhabitants of the region?
- 2) What are the archeological measures of various kinds of cultural interaction?
- 3) How did cultural interaction affect the evolution of local cultures?

"Interaction" is defined as a mutual action or influence (Hanks 1986) and can refer to the flow of material, ideas, or information. "Local" indicates the cultures and archeological material from within the southern Jornada Mogollon culture subarea as defined by Lehmer (1948) and "nonlocal" refers to areas beyond. The actual boundaries of prehistoric cultural systems are unknown and may or may not have been isomorphic with this archeological culture subarea (Willey and Phillips 1958).

The activity of defining culture areas - zones of shared culture traits - was one of the major tasks of archeologists from the early twentieth century to the 1960s. Diffusion and independent invention were the two primary processes by which culture change was explained. Examination of the historic spread of traits from center to periphery was the principal way in which intersocietal interaction was measured and a primary methodology for archeological explanation (Schortman and Urban 1987:41-44; see Chapter 3.0 for a review of role of diffusion in the development of the archeology of the Jornada Mogollon area). The concept of diffusion incorporated numerous distinct processes and had a number of serious shortcomings

including the ability to demonstrate that the movement of traits was due to intercultural contact; to specify the mechanisms of diffusion, especially the spread of innovations versus migrations of people; to explain why some traits were adopted and others were not; and to assess the effects of a new trait on a local culture (Schortman and Urban 1987:45).

Although many of these issues were never resolved, some inroads were made in the late 1950s and early 1960s. For example, a culture-contact classification scheme based on type of contact (migration versus trait movement), sizes of interacting populations, and the effects of contact on interacting populations formed a preliminary examination of cross-cultural patterns of intersocietal interaction (Willey and Lathrap 1956; see Schortman and Urban 1987:45). Caldwell's interaction sphere model that proposed that widely scattered populations could share ideological, social, and trade connections and yet retain their distinctiveness was significant from an evolutionary perspective. Participation in an interaction sphere was suggested to have been the foundation from which more complex societies developed (Schortman and Urban 1987:46). By the 1960s, however, these contributions were overcome by the resurgence of an evolutionary perspective and an emphasis on adaptation to the local environment within a systemic, cultural-ecological perspective dedicated to discovering law-like generalities. Diffusion's historical particularism and self-fulfilling characteristics, coupled with the inherently cultural explanations it provided, as well as its vagueness, resulted in its discard as a useful analytic construct. As a result, diffusion's impact on culture change was considered to be inconsequential as archeologists turned to an evolutionary functionalism focused on local ecological adaptations as the best way to understand culture change. However, further investigation of the conditions and consequences of intersocietal contact continued through the examination of various types of trade, warfare, and other forms of interaction as archeologists

struggled to assess the role of intersocietal contact in culture change. In the past 15 years Southwestern archeologists have been searching for conceptual tools that consider the regional context of local cultural evolution (e.g., Cordell and Gumerman 1993; Gumerman 1994; Mills and Crown 1995). For example, S. Plog (1995) suggests that interaction develops for an array of demographic, social, economic, religious, and political factors and that exchange is an expected characteristic of almost all societies of all levels of organizational complexity.

Trade, with its focus on the peaceful movement of goods between two or more societies, can be empirically verified with an array of compositional analyses summarized below. The identification of nonlocal material confirms the existence of interaction, but determining the nature of the relationship between societies is a far more complex issue (Schortman and Urban 1987:50). An array of models of trade has been proposed; the most relevant to the Jornada Mogollon region involve hunter-gatherers, village agriculturalists, and middle-range or chiefdom-like levels of political organization. Buffering exchange provides economic security against stochastic environmental change by spreading the risk of subsistence failure across a large region (Spielmann 1991:4-5). The exchange of craft and ritual items maintains intersocietal relationships that can be relied upon to gain access to resources in times of scarcity. Buffering models include the exchange of durable items for food in times of need (Spielmann 1991:4). However, climatic extremes and resulting environmental productivity frequently impact large regions resulting in low levels of spatial variation. As a result all communities in a region may experience shortages, simultaneously reducing the effectiveness of buffering exchange (Dean et al. 1985; Spielmann 1991:4). Mauldin (1995) has demonstrated that climatic patterns across much of southern New Mexico, including the study area, are correlated.

Mauss (1954) emphasized reciprocal gift exchanges that maintain useful alliances at several organizational levels, including intersocietal.

These alliances may serve numerous purposes including buffering mechanisms and devices for maintenance of prestige. For example, south African Bushmen participate in reciprocal gift-giving among trading partners (Kelly 1995:188-189). Gifts are not retained but are traded in-turn to other partners. Among the Bushman, most trading partners live within 40 km of each other, but partners may live as far as 200 km apart (Kelly 1995:188). Ethnographic evidence from several hunter-gatherer groups suggests that in times of resource scarcity families go to live with trading partners (Kelly 1995; Spielmann 1982).

Mutualistic exchange may emerge when resource distributions are heterogeneous. Societies exploiting different ecological settings may emphasize the production, for exchange for mutual benefit, of complementary resources (Spielmann 1991:5). High resource abundance and predictability coupled with low production costs favor the formation of some degree of specialization and mutually beneficial exchange.

World systems theory, first proposed by Wallerstein (1974), offer a set of conceptual tools providing a systemic approach to macroregional interactions while considering multiple causations and variables that contribute to cultural change, all within an economic framework (Schortman and Urban 1987). The interrelationships among cores, semiperipheries, and peripheries are the analytical focus of world systems theory and lead to an understanding of the growth of cores at the expense of peripheries. A number of Southwestern archeologists have attempted world systems analyses, including consideration of Mesoamerican-Southwestern interactions (e.g., Whitecotton and Pales 1986; Wilcox 1986). While archeologists have struggled with an array of models, all are dependent upon documenting the movement of materials across space. Our analytical tools for identifying nonlocal materials and their origins are substantial, but our ability to infer the nature of the interaction in behavioral terms is not well developed.

10.1 CHARACTERIZATION OF RAW MATERIALS

Only the artifacts themselves, or more specifically, the materials from which the artifacts are made, rather than their styles can identify the artifacts' origins. The characterization of the materials is a definition and revelation of the specific sources from which at least constituent parts of the artifacts are derived and invokes what Weigand et al. (1977) term the "Provenience Postulate."

Implicit in the idea of using chemical analysis to trace artifacts to their source, or to sort out and group together artifacts of unknown sources, is what may be termed the "Provenience Postulate," namely, that there exist differences in chemical composition between different natural sources that exceed, in some recognizable way, the differences observed within a given source. These differences are usually simply quantitative differences in concentration of chemical elements, but they can also be differences in relationship between concentrations of two or more elements (i.e., their correlation) (Weigand et al. 1977:24).

Numerous chemical and geological techniques are available to determine the characteristic chemical composition of specific sources. Some of these methods have already been employed in the study area and will continue to be used; others perhaps can be usefully applied in the study area to understand its interaction with regions beyond.

Several analytical methods are available for the study of a given object. Visual examination is, of course, an obvious starting point. A preliminary separation according to appearance is worthwhile; however, visual examination of artifacts or materials is generally not a reliable guide to their source: one must seek more in-depth analyses. For example, chert from different sources, when placed under ultraviolet (UV) light, give off distinctive colors (Hofman et al. 1991). This analytical method was used in a study carried out by Mauldin and O'Leary (1994) which revealed the presence of Edwards chert from Central Texas in the Tularosa Basin.

Church et al. (1994) in the three-year Fort Bliss Lithic Source Survey, also carried out studies utilizing and assessing the efficacy of ultraviolet fluorescence (UVF). They found its usefulness is varied given the UVF response of some of the minerals. In addition, this study generated a baseline of data providing identification criteria for the materials encountered in their sample of 228 lithic sources. The study also explored the utility of such analytical tools as magnetic susceptibility, natural radioactive emissions, bioclast analysis, and UVF.

Additional analytical methods include petrographic analysis (microscopic thin-sectioning), trace-element analysis, isotopic analysis, X-ray diffraction, infrared-absorption spectroscopy, fission-track analysis, and Mössbauer spectroscopy. A brief discussion of some of the more applicable methods that might be utilized in the study area is presented. Discussions of the methods pertinent to the study area are taken from Renfrew and Bahn (1991) and Parkes (1986) unless otherwise cited. Relatively few Paleoindian sites are known on Fort Bliss.

10.1.1 Petrographic Analysis

The study of the rock or mineral structure of artifacts has been common for some time (Shepard 1956). By cutting a thin section of an object and examining it under a microscope, it is possible to identify specific mineralogical characteristics of the sample. For example, examination of a thin section of a potsherd can reveal such constituents as ceramic temper, thus allowing specific clay and/or temper resources to be identified. Of course, samples from all possible clay sources are needed for building a database against which samples of artifacts are assayed. Petrographic analysis is one of the more common studies carried out on ceramics in the area. This type of analysis lends itself to answering questions regarding settlement, subsistence, and interaction (and changes in those systems) on local and regional levels (see Hill 1988, 1989, 1993; Rugge 1986, 1988; Smiley 1977; Southward 1979).

10.1.2 Trace Element Analysis

The basic composition of many materials is quite consistent. Obsidian, for instance, is broadly similar in its makeup of silicon, oxygen, calcium, etc. The trace elements (representing only parts per million in the stone's makeup) vary according to their source. The methods used to measure these concentrations, thus geographically differentiating their sources, are listed below.

10.1.2.1 Optical Emission Spectrometry

Optical Emission Spectrometry (OES) was the first of such methods to be archeologically applied, by Austrian archeologist R. Pittioni in the 1930s. In the 1950s and 1960s, OES was used in metallurgy and for the characterization of obsidian. It has now largely been replaced by Inductively Coupled Plasma Emission Spectrometry (ICPS) and by Atomic Absorption Spectrometry (AAS). OES is based on the principle that the electrons of the atoms of every chemical element, when excited (e.g., heated to a high temperature), release light (and hence color) of a particular wavelength. A sample is burned in a carbon arc. The light given off is composed of different wavelengths and can be separated into a spectrum when passed through a prism or diffraction grating. The presence or absence of the various elements can be established by looking for the appropriate spectral line of their characteristic wavelengths. The results are expressed in percentages for the more common elements and parts per million (ppm) for the trace elements.

10.1.2.2 Inductively Coupled Plasma Emission Spectrometry

Inductively Coupled Plasma Emission Spectrometry (ICPS) is based on the same principles as OES but the sample in the solution is atomized and excited in a plasma rather than in a carbon arc. A much higher temperature can be reached, which reduces problems of interference between elements. ICPS has been largely automated, so that an extremely high volume of assayed samples can be achieved. This method has

been used in the characterization of pottery, chert, obsidian, and copper and bronze.

10.1.2.3 Atomic Absorption Spectrometry

The principles behind Atomic Absorption Spectrometry (AAS) are similar to those used in OES (i.e., the measurement of energy in the form of visible light). The sample to be analyzed (between 10 mg and 1 g) is dissolved in acid, diluted, and then heated by spraying it onto a flame. Light of a wavelength that is absorbed by the element of interest (and only that element) is directed through the solution. The intensity of the emergent light beam is measured with a photomultiplier. The concentration of the particular element is directly related to the intensity of the beam. By using different wavelengths of light, over 40 elements can be measured. The method has the disadvantage of being slow and destructive. It does have a particular advantage over other methods in detecting metals, such as lithium and sodium, which have low atomic numbers. AAS has been used for the analysis of nonferrous metals, such as copper and bronze, chert artifacts, and other materials.

10.1.2.4 Neutron Activation Analysis

Neutron Activation Analysis (NAA) is a method of trace-element characterization that came into widespread use in the 1970s and has been used for obsidian, pottery, metals, and other materials. It is an entirely nondestructive process; however, using this method will often render whole objects radioactive, delaying for several years their safe return to the museum, archeologist, or whomever. This method depends on the excitation of the nuclei of the atoms of a sample's various elements when these are bombarded with slow neutrons. In order to do this, the samples (about 50 mg) are placed in a metal can in a nuclear reactor and bombarded with a beam of neutrons. The irradiation transforms the atomic nuclei of the elements in the sample into unstable radioactive isotopes (nuclides) which release gamma rays as they decay into stable isotopes. The energy levels of the gamma rays are characteristic of the

particular element excited. Measuring the gamma-ray energy emitted by a sample therefore indicates the elements present. The intensity of each spectral line shows the quantity of each element. This method has the advantage of measuring concentrations ranging from 1 ppm to 100%, and it can be automated, so that numerous results can be achieved relatively quickly.

The first characterization of turquoise in the Southwest was conducted by Sigleo (1975). Trace element analysis was conducted by Instrument Neutron Activation Analysis (INAA) on turquoise from 24 mines in the Southwest, including samples from Orogrande in the Jarilla Mountains, New Mexico, near Fort Bliss. Weigand et al. (1977:15-34) adopted neutron activation as an analytical procedure in their work on turquoise sources and source analysis in Mesoamerica and the Southwestern United States. Bentley (1994), working on Fort Bliss, has utilized INAA in a geochemical characterization of clay sources in the study area.

10.1.2.5 X-ray Fluorescence Spectrometry

Known as XRF, X-ray Fluorescence Spectrometry utilizes a sample irradiated with a beam of X-rays which excite electrons in the surface. The electrons revert to their original positions when the X-ray beam is switched off, but as they do, they emit secondary or fluorescent X-rays. The energies and wavelengths of these secondary X-rays correspond to the concentrations of elements in the sample (each element emits X-rays of a characteristic energy). XRF analysis is usually accurate to between $\pm 2\%$ and $\pm 5\%$. This method has been used on materials such as metals, obsidian, and pottery. It has been particularly useful for examining glazes on pottery. Bradley and Hoffer (1985:161-177) utilized XRF to assess patterning in the chemical content of Playas Red sherds from different sites in the Jornada Mogollon and Casas Grandes regions. XRF data on obsidian were used to determine probable sources and geochemical variability for samples recovered from the Border Star 85 archeological survey (Shelly et al. 1988:149-162).

10.1.2.6 Proton Induced X-ray and Gamma-ray Emission

Proton Induced X-ray Emission (PIXE) and Proton Induced Gamma-ray Emission (PIGME) are similar in principle to XRF and NAA but, instead of X-rays or neutrons, the exciting agent is a beam of protons produced by a Van de Graaff accelerator. The secondary radiation given off by the sample is again either X-radiation or gamma radiation. PIXE and PIGME are used together, with the former being employed for the majority of elements and the latter for those with low atomic weight (e.g., fluorine, sodium, and aluminum), which are less suitable or unsuitable for X-ray measurement.

10.1.3 Fission-track Analysis

This analytical method is mainly a dating method, but has also been used to distinguish between obsidian sources on the basis of their uranium content and the date of the formation of the deposits.

10.1.4 Mössbauer Spectroscopy

This method is used in the study of iron compounds, notably in pottery. It measures the gamma radiation absorbed by the iron nuclei, which gives information about the particular iron compounds in the pottery sample and on the conditions of firing when the pottery was being made.

10.1.5 Isotopic Analysis

The application of isotopic chemistry to metal sourcing has produced very successful results. It has become the most important characterization technique for metal objects because it successfully distinguishes lead from different sources in a way that trace-element analysis has failed to do. The method is of direct use not only for lead artifacts, but also for silver (lead is usually present as an impurity) and copper. Copper sources always contain at least a trace of lead, and it has been shown by experimentation that a large proportion of that lead passes into the copper metal produced

during smelting. The obvious impact of this type of study on the copper bells found in the region would illuminate further the ideas of spheres of influence from the south and Southwest.

Recently, isotopic analysis has been undertaken to characterize the differences among turquoise mining districts, including Orogrande (Mathien 1995). Initial results indicate that there are differences in the amount of lead in turquoise samples from mines in the Southwest and one source from Chihuahua. Additionally, differences are seen in lead isotopes ($^{208}\text{Pb}/^{207}\text{Pb}$) from the Cerrillos mining district and five other mining districts in the American Southwest. Future research efforts can perhaps bring light to the role of the Orogrande mining district in cultural interaction with Paquimé to the south during Formative times.

Isotope ratios have also been used in the characterization of obsidian (strontium isotopes). Measuring ratios of $^{87}\text{Sr}/^{86}\text{Sr}$ in volcanic materials, such as obsidian, can be very useful in identifying the sources of materials. Strontium is chemically extracted from artifacts and sources, then their isotopic composition is determined using a mass spectrometer. The rubidium (Rb) and strontium concentrations in the samples are also determined either by mass spectroscopy or wavelength dispersive X-ray fluorescence analysis. By plotting the $^{87}\text{Sr}/^{86}\text{Sr}$ ratio against Rb content, a distinction between sources can be made. This technique seems to offer a fast and inexpensive method of discrimination between material sources.

Oxygen isotope ratios have proved useful for the characterization of marine shell. Temperature, salinity, species type, calcite-to-aragonite ratio, and geological environment affect the chemical composition of marine shell. The majority of factors, except for species, are environment related. Differing trace elements in the shells of mollusks of the same species would be expected to reflect geographically based differences in the environment given their difference in water temperature, salinity, sedimentological and geological-related discrepancies or differences

(Bradley 1992:142). A new technique is being tested for its effectiveness in determining source areas for shell from the Gulf of California. This chemical analysis uses the technique of emission spectroscopy (Bradley 1992:140).

10.1.6 X-ray Diffraction Analysis

This method is used to identify the crystalline structure of minerals based on the angle at which X-rays are reflected. X-ray diffraction has been used extensively in the analysis of pottery clay sources. In their study of turquoise sources and source analysis of areas in Mesoamerica and the Southwestern United States, Weigand et al. (1977:15-34) carried out numerous X-ray diffraction experiments, producing a more positive identification of various local minerals.

Table 14 summarizes the most appropriate characterization methods for some archeological materials. An important note in regard to sourcing of materials by characterization studies is that these studies very much depend upon the knowledge of the natural distribution of the raw materials. Additionally, it is important to keep two factors in mind: the extent to which the raw material from which the artifact is made is changed during its archeological context, and the extent to which the raw material was changed during the production of the artifact.

10.2 DIACHRONIC INDICATIONS OF CULTURAL INTERACTION

Throughout the prehistory of the study area, evidence of interaction with other regions exists. During the Paleoindian period, nonlocal lithic raw material has been identified. The Archaic period evidence is dominated the presence of projectile point styles that are common outside the local area. By Formative times, nonlocal ceramic types are the most common indicator of interaction, although other exotic items (including copper bells and shell) have been found as well. By the El Paso phase, evidence of interaction is at its apex.

Table 14 Assays Suitable for Characterization of Archaeological Materials.

| Material | XRF | NAA | AAS | ICPS | PIXE | PIGME | Other |
|----------------|-----|-----|-----|------|------|-------|--|
| ceramic | yes | yes | yes | yes | yes | yes | petrological thin section, X-ray diffraction, Mossbauer spectroscopy |
| chert/flint | yes | yes | yes | yes | yes | yes | |
| obsidian | yes | yes | yes | yes | yes | yes | fission track |
| other lithic | | | | | | | petrological thin section |
| marine shell | | | | | | | carbon & oxygen isotope |
| copper, bronze | | yes | yes | yes | | | lead isotope |
| iron ores | | | | | | | Mossbauer spectroscopy |

10.2.1 Paleoindian

Paleoindian occupations in the area date from between 11,000 to 8000 BP, and are represented by a few sites, some of which produced numerous projectile points and other tools. Small amounts of nonlocal material- including Edwards chert, which has its source over 500 km to the east in central Texas, and Chuska chert, originating over 480 km to the northwest - have been found on sites in the area (Mauldin and O'Leary 1994). Amick (1995:29) has suggested that variability in Folsom site raw material indicates a systemic connection between land use in the southern Plains and the southwestern basin and range country. It remains unknown however, if these distant raw materials were brought to the area by the individuals who deposited them or if they were transported into the area through trade. Kelly and Todd (1988) suggest that Paleoindian hunters and gatherers engaged in high levels of residential mobility, moving vast distances across the North American landscape, going from kill to kill with little use of storage. Paleoindian projectile point styles are characterized by their vast geographic distributions, particularly in contrast to the regionalization of styles in later millennia. Kelly and Todd (1988) suggest these distributions are related to continental-scale social networks.

10.2.2 Archaic

Archaic projectile points represent a mixture of styles common to the west, east and north of the project area (cf. Beckes 1977; Carmichael 1986; MacNeish 1993; O'Hara 1988; MacNeish 1993; Skelton et al. 1981). The three adjacent regions are the Trans-Pecos, located to the east and southeast (Mallouf 1985; Suhm and Jelks 1962; Turner and Hester 1985); the Cochise, originally described by Sayles and Antevs (1941), extending from eastern Arizona through New Mexico and into northern Mexico; and the Oshara, first defined by Irwin-Williams (1973) based on excavations of sites near the Puerco River in north-central New Mexico. In addition, at least one type, the Livermore point, is common to the Big Bend region of Texas (Lehmer 1948:30).

Despite almost a century of attention, the meaning of such stylistic patterns is not well understood. Stylistic traits are known to change across space and are not isomorphic with linguistic or breeding population boundaries (e.g., Binford and Sabloff 1983; Wissler 1922). Locations on the edges of these distributions typically share overlapping stylistic traits with two or more adjacent regions (Binford and Sabloff 1983). Therefore it is not surprising that the study area contains Archaic projectile point styles of adjacent regions, and it is a truism such similarities reflect interaction with the adjacent regions. Unfortunately the nature and

causal priority of these interactions remain poorly understood.

Lehmer (1948:71-74) notes that shell beads made from *Olivella* and bracelets and pendants from *Glycymeris* were recovered from Archaic period (formally known as Hueco) contexts. Both taxa derive from the Gulf of California or the Pacific coast of Baja California. MacNeish (1993:292-296) and his colleagues also recovered *Olivella* shell beads from the Archaic levels at Todsen Cave.

The introduction of cultigens into the southwest has been a significant research topic since the early twentieth century. Maize was present in the area by 3000 BP (Upham et al. 1987:410-419). According to Upham and his colleagues (1987), Chapalote's diffusion from Mesoamerica to the Southwest followed a route from somewhere in Zacatecas to central Chihuahua, continuing north to the Jornada region (Upham and MacNeish 1993:113).

10.2.3 The Formative Period

10.2.3.1 Ceramics

The local manufacture of El Paso brownwares defines the Formative period for the Mesilla, Doña Ana, and El Paso phases (see Chapter 3.0). During the Mesilla phase (A.D. 250-1150), Mimbres Black-on-white pottery from southwestern New Mexico is the primary intrusive pottery, appearing during the ninth century A.D. and continuing into the Doña Ana phase (A.D. 1150 to 1250) (Hard et al. 1994; Whalen 1981:80). In addition there are sporadic occurrences of other Western Mogollon wares such as San Francisco Red and Alma Plain (Marshall 1973:5; Whalen 1979:357). The occurrence of these nonlocal Western Mogollon ceramics (see Figure 37 and Table 15) suggest interaction with western and southwestern New Mexico. The later Mimbres Black-on-white Transitional and Classic styles are more frequent than the earlier Mimbres Boldface in the study area, suggesting that the frequency of

interaction increases in the eleventh and twelfth centuries (Whalen 1979:357; 1994:75).

Recently Harry Shafer and Darrel Creel and their colleagues have been conducting neutron activation analysis (NAA) on sherds from the Mimbres and the El Paso areas (Creel et al. 1995; Shafer et al. 1995). Although much of their work is not yet published, one study examined decorated and undecorated Mimbres white-slipped brownware sherds found on Mesilla phase sites in the southern Jornada area and El Paso brownwares found on Mimbres Valley sites, these were compared to Mimbres sherds from the Mimbres Valley and the Upper Gila River valley (James et al. 1995). The Mimbres white-slipped brownware sherds from the southern Jornada area were compositionally similar to Mimbres Valley and Upper Gila River valley sherds, suggesting they were manufactured in the Mimbres area. In addition, eight El Paso brownware sherds found on the NAN Ruin, a Mimbres Valley Site, were similar to El Paso Brown, El Paso Bichrome, and El Paso Polychrome sherds from the southern Jornada area. As a result, these investigators suggest that bilateral ceramic exchange between Mimbres and southern Jornada peoples were occurring (James et al. 1995). Creel and his colleagues (1995) report similar results, indicating that the composition of Mimbres Black-on-white sherds found in the vicinity of the study area affiliate with sherds from the Mimbres area, rather than sherds from the southern Jornada area. However, they have also found that there are several distinct compositional clusters represented in the Mimbres area sherds.

Gilman et al. (1994:695-709) reports similar results, although they did not examine sherds from the study area. They find through an NAA analysis of 117 samples from six sites in the Mimbres and Upper Gila River valleys that a number of distinct production groups are present. These recent NAA results may explain earlier petrographic analyses of Mimbres Black-on-white pottery from the Jornada area that had suggested at least some of the pottery was locally made in the study area. Rugge (1985, 1988) found a high degree of heterogeneity in the temper of Mimbres

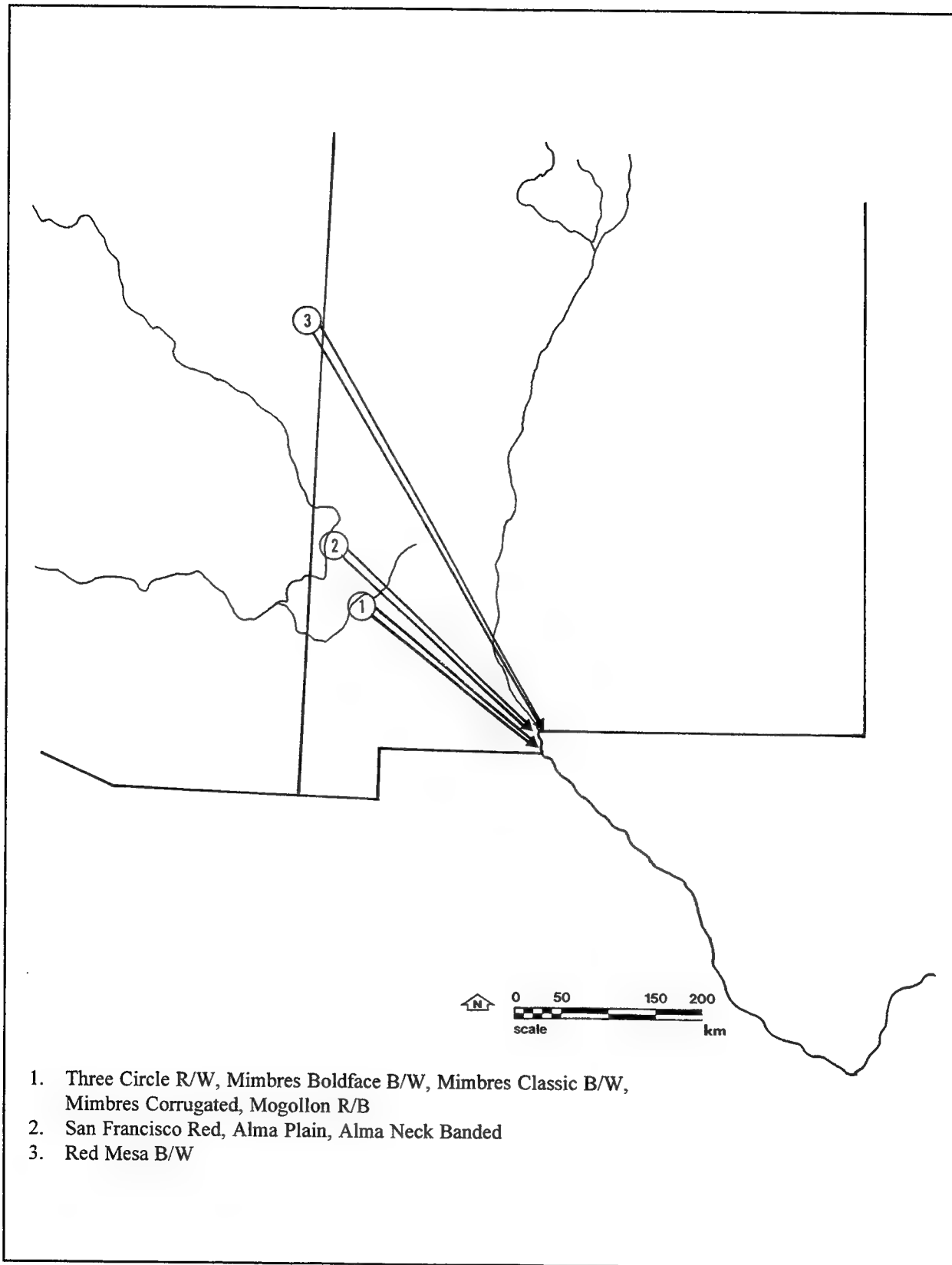


Figure 37 Source Areas of Intrusive Ceramics During the Mesilla Phase.

Table 15 Intrusive Ceramic Types During the Formative.

| Predominant Region | Ceramic Type | Mesilla | Doña Ana | El Paso |
|----------------------------|--------------------------------------|---------|----------|---------|
| Three Rivers | San Andres Red-on-terracotta | | • | • |
| | Three Rivers Red-on-terracotta | | • | • |
| | Lincoln Red-on-black | | | • |
| Middle Rio Grande | Chupadero Black-on-white | | • | • |
| | Los Lunas Smudged Corrugated | | | • |
| | Corona Rubbed | | | • |
| Upper Rio Grande | Galisteo Black-on-white | | | • |
| | Agua Fria (Glaze A) | | | • |
| | Arenal Glazed Polychrome | | | • |
| Western Mogollon | Three Circle Red-on-white | • | | |
| | Mimbres Boldface Black-on-white | • | | |
| | Mimbres Classic Black-on-white | • | • | |
| | Mimbres Corrugated | • | • | |
| | Mogollon Red-on-brown | • | | |
| | San Francisco Red | • | | |
| | Seco Corrugated | | | • |
| | Alma Plain | • | • | • |
| | Alma Neck Banded | • | | |
| Little Colorado River | Red Mesa Black-on-white | • | • | |
| | Wingate Black-on-red | | • | • |
| | St. Johns Polychrome | | • | • |
| | Heshot-uthla Polychrome | | | • |
| | Kwakina Polychrome | | | • |
| Southeast New Mexico | Ochoa Brown Smudged | | | • |
| Central & Southern Arizona | Gila Polychrome | | | • |
| | Tucson Polychrome | | | • |
| Northern Chihuahua | Playas Red (<i>see text</i>) | | • | • |
| | Casas Grandes Plain | | | • |
| | Casas Grandes Tool Punched | | | • |
| | Ramos Polychrome (<i>see text</i>) | | • | • |
| | Villa Ahumada Polychrome | | | • |
| | Carretas Polychrome | | | • |
| | Corralitos Poly Textured | | | • |
| | Convento Rubbed Corrugated | | | • |

sherds, and some temper types appeared similar to rock types found adjacent to the Hueco Bolson and Tularosa Valley, leading him to suggest local production. Although it has yet to be confirmed, this heterogeneity is likely a reflection of the diverse Mimbres area production localities that the NAA studies have identified, rather than the result of Mimbres Black-on-white being manufactured in the study area.

Gilman et al. (1994) suggests that the manufacture of Mimbres ceramics was not centralized but derived from diverse locations within the Mimbres and Gila River valleys and that these populations were organized in a nonhierarchical fashion. They suggest that the distribution of vessels in the Mimbres region may be accounted for by the movement of peoples between the Mimbres Valley and other locations, perhaps on a seasonal basis.

Not only do Mimbres Black-on-white ceramics occur on Doña Ana phase sites, but there is a sharp increase in the number of nonlocal wares present in the study area (Table 15, Figure 37). These include Chupadero Black-on-white, Three Rivers Red-on-terracotta, San Andres Red-on-terracotta, Wingate Black-on-red, St. Johns Polychrome, Ramos Polychrome, and Playas Red (Carmichael 1986; Hard et al. 1994; Kegley 1982; Smiley 1977:130).

Limited chemical characterization work has been conducted on these intrusives and therefore it is usually assumed that nonlocal types were manufactured in the areas where they were most common. In lieu of compositional analyses we will provisionally continue this practice. Chupadero Black-on-white is, by far, the most common Doña Ana phase (and El Paso phase) intrusive and it may have derived from the middle Rio Grande region of central New Mexico, particularly the Chupadera Mesa region and Gran Quivira. Warren (1981) conducted petrographic studies and concluded Chupadero Black-on-white sherds from Gran Quivira were made there. However, there is also evidence that Chupadero Black-on-white was made in the Sierra Blanca region as well, which would place its origin within the northern Jornada area (Kelley 1979; Wiseman 1986).

The red-on-terracotta series is thought to have derived from the northern Tularosa Basin, between the Capitan and San Andres mountains within the northern Jornada area. Three Rivers Red-on-terracotta was widely distributed across central and southern New Mexico but was very abundant at a site at Three Rivers, New Mexico (Runyan and Hedrick 1973). From sites within the study area the Three River redwares are roughly the fourth most common intrusive type for all time periods.

The White Mountain redwares (Wingate Black-on-red and St. Johns Polychrome) are rare on Doña Ana phase sites. White Mountain redwares are widely distributed throughout much of the Southwest, but are the most common in the eastern portion of the Little Colorado River area of

western New Mexico and eastern Arizona (Carlson 1970).

Playas Red, and its varieties were present in the Doña Ana phase and continued to be manufactured in the El Paso phase. Traditionally it was assumed to have originated from Casas Grandes where it is common. However, Wiseman (1981) suggested it was being made in the Sierra Blanca region. Bradley and Hoffer (1985), as a result of an XRF analysis of 69 sherds of Playas Red from five regions, presented evidence that there were multiple manufacturing loci for this type. The composition of sherds from within each of the five regions was highly similar, but dissimilar among the regions, suggesting several manufacturing areas. However, sherds from within the Rio Grande, southern Jornada, and northern Jornada areas were intermixed to some degree. Surprisingly, it appeared that none of the Playas Red found in the Jornada area originated from Casas Grandes, although a few Playas sherds from the southern Jornada could have originated from Janos, Chihuahua. Creel et al. (1995), as a result of an NAA study, also suggests that Playas Red from the Jornada area was made in the Jornada area.

Ramos Polychrome is also assumed to be a Casas Grandes intrusive by most investigators since it was the most common polychrome recovered from the site of Casas Grandes. However, it too represents a more complex picture. DeAtley and Findlow (1982) conducted a stylistic analysis of Ramos Polychrome designs on jar sherds from Casas Grandes and compared them to sherds from four valleys in the Animas area in extreme southwestern New Mexico. They found only slight evidence of stylistic similarity between the New Mexico and Casas Grandes design styles and suggested that the Animas sites were largely independent of Casas Grandes. Woosley and Olinger (1993) conducted an XRF study of 382 Ramos Polychrome sherds from Casas Grandes, 27 other Chihuahuan sites, sites in the Sulphur Spring Valley of Arizona, and a site from the Animas area in southwestern New Mexico. They found that sherds from Casas Grandes and sites up to about

80 km from Casas Grandes were all similar in composition and macroscopic characteristics. However, the Arizona and New Mexico sherds were distinct from each other and from the Chihuahuan sherds both chemically and macroscopically. They concluded that Ramos Polychrome was being manufactured at or near Casas Grandes and distributed up to 80 km. But they also concluded that the Ramos Polychrome sherds from Arizona and New Mexico were not made in northern Chihuahua.

The diversity of intrusives present in the Doña Ana phase increased in the El Paso phase (see Table 15 Figure 38). Mimbres Black-on-white is no longer present in the El Paso phase, as the Mimbres occupation had ceased to exist (e.g., Hard et al. 1994). Lincoln Black-on-red, a Three Rivers redware, occurred at this time. It occurs in the greatest density in the northern Jornada area, including the northern Tularosa Basin and Sierra Blanca where it originated (Kelley 1984; Runyan and Hedrick 1973). Evidence of interaction with the northern Rio Grande region occurred for the first time in the El Paso phase with the occurrence of a few sherds of Galisteo Black-on-white, Agua Fria Glaze A, and Arenal Glazed Polychrome (e.g., Carmichael 1986; Smiley 1977).

Interaction with southeastern New Mexico is represented by a few sherds of Ochoa Brown in the study area. Gila Polychrome occurred in small numbers on El Paso phase sites. Gila Polychrome was widely distributed throughout large portions of the Southwest. Crown (1995), as a result of a NAA study, concluded that Gila Polychrome was made at multiple locations in the Roosevelt-Tonto Basin region in central Arizona. Salado interaction was also indicated by the presence of Tucson Polychrome, a type thought to derive from the San Pedro River region in southeastern Arizona (Oppelt 1976).

By the El Paso phase, the evidence for interaction with Casas Grandes is indicated by the presence of small numbers of sherds of Villa Ahumada Polychrome, Carretas Polychrome, Corralitos Textured Polychrome, and Convento Rubbed

Corrugated. Playas Red and its varieties were still occurring in the El Paso phase and may have been manufactured in the Jornada area. Ramos Polychrome also continues to be present in the El Paso phase and may not have been made at Casas Grandes either. In summary, the intrusive ceramic data includes evidence of interaction with most surrounding regions, including the northern Jornada area, northern Rio Grande, western Mogollon, White Mountain region, northern Chihuahua, southeastern New Mexico, and central and southeastern Arizona. Clearly, El Paso phase society was involved in a greater level of interaction, with more regions than previous occupations (Beckes et al. 1977; Carmichael 1986; Lehmer 1948:81-82; Smiley 1977; Whalen 1977, 1978). However, using the frequency of intrusive sherds as an indicator, interaction with areas to the north, particularly the northern Jornada region, far outweighs interaction with any other region including Casas Grandes (see Lehmer 1948; Carmichael 1986). All other intrusives occur in small quantities.

10.2.3.2 Ornamental Objects

Ornamental objects occurred on prehistoric sites in the Jornada region from the Archaic period through the El Paso phase, and they appear to have increased in frequency over that time. These objects include copper bells, items of shell and turquoise, and ceremonial items.

Shell

Shell ornaments have been found in several sites that were intensely occupied from Archaic to El Paso phase times (e.g., Lehmer 1948; Whalen 1994:128). Los Tules, the type site for the Mesilla phase, contained numerous, well-made shell ornaments (Lehmer 1948:28-29). Bracelets and pendants were made of *Glycymeris* shells and beads were drilled *Olivella* shells. Small quantities of *Olivella* and *Glycymeris* marine shell have been recovered from other Mesilla phase sites in the Hueco Bolson and surrounding areas (Whalen 1977, 1978, 1994). Whalen (1994:127) recovered 14 shell ornaments from the Turquoise Ridge site,

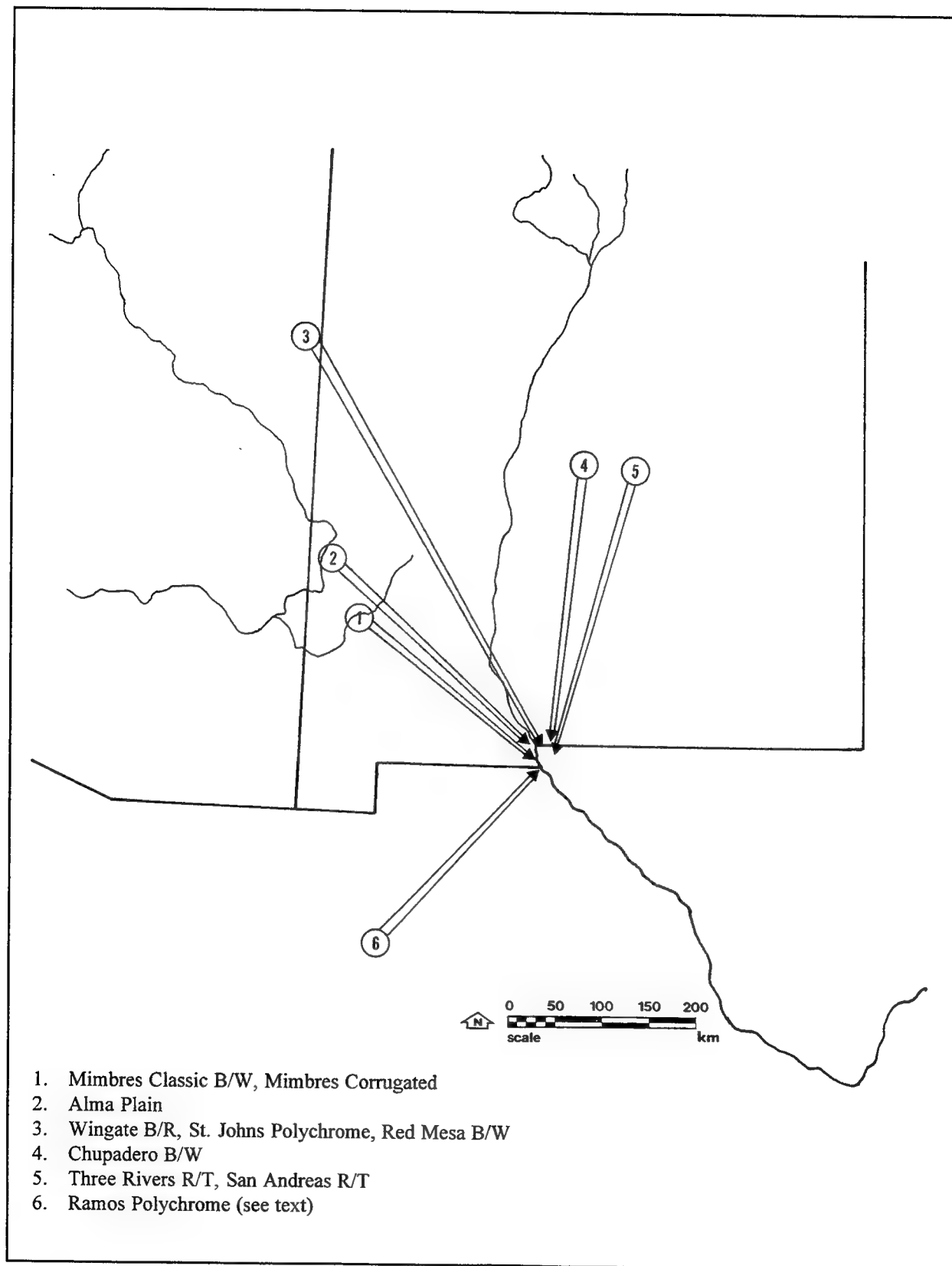


Figure 38 Source Areas of Intrusive Ceramics During the Doña Ana Phase.

12 of which came from a postulated communal building dating to A.D. 820 \pm 60. This structure also contained the majority of turquoise and Mimbres Black-on-white pottery found on the site. Specimens of *Olivella*, *Glycymeris*, and *Pyrene* were identified.

Southward (1979:91-102) reported that a village site near Three Rivers, New Mexico, contained *Glycymeris*, *Olivella*, and *Vermetus* shell. Excavations at Todsens Cave produced a small number of shell beads and bracelets from zones associated with the Archaic through El Paso phases (MacNeish 1993:290-296). He reported four *Olivella* beads from Archaic contexts, five *Glycymeris* shell bracelets from Mesilla to El Paso phase contexts, and four *Cardium* beads from Mesilla to El Paso phase contexts, and a conch shell piece from the Mesilla phase. MacNeish's (1993:291) identification of *Cardium* is suspect, as this is a north Atlantic species and not found in the Southwest. The Alamogordo sites yielded *Glycymeris*, *Vermetus*, and *Olivella* beads, *Conus* shell tinklers, and *Glycymeris* bracelets (Lehmer 1948:61-62). Substantial quantities of shell artifacts have also been recovered from caches from the region and are discussed below.

Olivella is found throughout the Gulf of California as far south as Mazatlan (Bradley 1996). *Glycymeris* comes from both the Pacific and Gulf of California sides of the Baja peninsula (Bradley 1996). *Pyrene* is found in the shallow waters off the Gulf of California and as far south as Peru along the Pacific coast. *Vermetus*, a marine worm, is indigenous to the shallow waters of the Gulf of California. All shell found in the southern Jornada area could have derived from the Gulf of California or possibly the Pacific coast of Baja California. Bradley (1996) conducted a study of the stylistic characteristics of southwestern prehistoric shell, including shell from the Alamogordo sites and an unpublished site known as Firecracker. The southern Jornada area shell styles clustered with shell from the Western Pueblo, Salado, Mogollon, and Casas Grandes regions and not the early Anasazi and Hohokam (Bradley 1996:120-121). It would appear that the

inhabitants of the southern Jornada area were participating in a large shell-distribution network that stretched from Casas Grandes to central Arizona, and included the Salado region, the Upper Rio Grande, and Pecos Pueblo.

Copper Bells

Lehmer reported that two copper bells were found at the El Paso phase Bradfield site, but he was unable to examine them (Lehmer 1948:70). He was, however, able to observe collections with several other copper bells from other El Paso phase sites. "Although badly distorted, the resonators seem to have been spherical, slit at the bottom, and slightly flattened at the top where the eyelet is attached" (Lehmer 1948:53).

Bradley (1992:127) notes that copper bells of styles similar to those in Mesoamerica were found in the Southwest as early as A.D. 900 to 1000. After A.D. 1200, Casas Grandes may have become the production center and major exporter of bells to sites in the Southwest (Mathien 1992:46; McGuire 1992:101). Casas Grandes is the only site within the Southwest that has evidence for the manufacture of copper ornaments (Bradley 1992:127).

Religious or Ceremonial Objects

Items and symbols attributed to ceremonialism, some of which have been found in rockshelters, are suggestive of nonlocal interaction. Twenty-one *tablitas* were uncovered in excavations of two rockshelters (O'Laughlin 1977). *Tablitas* are the altar decorations or headdresses used by modern Pueblo and Apache Native Americans. They were made of soapstone yucca and some were painted black, red, or black and red. Some have opposing stepped elements of black and red, suggesting continuity between the design elements of *tablitas* and El Paso Polychrome pottery (O'Laughlin 1977:175). East Cave contained 20 of the fragments, all from ceramic bearing levels, the remaining one came from West Cave. O'Laughlin notes they could date either to the Mesilla or El Paso phases. He notes that Cosgrove recovered

fragments of *tablitas* in Ceremonial Cave and three other caves in the mountains of the survey area, and suggests they also date to ceramic times but could possibly be earlier.

The geographic distribution of *tablitas* at about A.D. 1300 includes extreme west Texas, southern New Mexico, and east central Arizona (Cosgrove 1947:132-134; Lambert and Ambler 1961:77-78; Martin et al. 1952:421-422; Wasley 1962; as summarized by O'Laughlin 1977:175). O'Laughlin noted that aspects of the Kachina cult, *tablitas* and kiva bowls (bowls with terraced designs applied to the rim), are found only in the Jornada region of the Mogollon around A.D. 1300. Both *tablitas* and kiva bowls have analogous counterparts in modern Pueblo societies but archeologically are not known from the fourteenth century in those areas. Rock art studies carried out by Schaafsma and Schaafsma (1974) argued that the Kachina cult and associated religious sodalities arrived in the Upper Rio Grande in the early fourteenth century from the Jornada region of the Mogollon, where they or their prototypes had been present for perhaps 150 years (Schaafsma and Schaafsma 1974:544). However, the Schaafsma's dating of the rock art is tentative at best, as they infer that, based upon the use of similar motifs, it is contemporaneous with Mimbres Boldface and Classic pottery types. However the rockart in the Mimbres area at this time is distinctive from the eastern Jornada rockart style found in the study area (Adams 1991:88). Alternatively Adams does not see a Jornada area origin for the Kachina cult, but argues that a separate Jornada cult blended with the western Pueblo Kachina cult in the northern Rio Grande Valley during the fifteenth century (1991:118, 123). Jornada style rockart, such as that at Hueco Tanks State Park, contains elements including the plumed serpent and horned serpent. The serpent figures have sometimes been identified as resembling Quetzalcoatl, a Mexican deity (Adams 1991:123; Schaafsma and Schaafsma 1974; Schaafsma 1975). Tlaloc, a Mexican rain god, is recognized on the basis of a pointed head in rockart in the Jornada. Rockshelters contain goggle-eyed anthropomorphic figures in the project area at Picture Cave, and at Hueco Tanks, east of

the project area. These figures have been compared and associated with the Tlaloc figures seen in central and northern Mexico.

Almarez and Leach note that some of the rock art recorded in their survey of Tlaloc is associated, for example, with Teotihuacan and the Classic period. Almarez and Leach (1995) note that in the Jornada, his depiction is more abstract, but the basic elements are recognizable.

Pictographs and petroglyphs of plumed serpents, horned serpents, and associated human forms, all seemingly associated with the iconography of Quetzalcoatl are found within or near caves and rockshelters in the Franklin and the Hueco mountains (Bentley 1992b; Brooks 1979:38). Bentley (1992b:37) also reported the recovery of a carved bone effigy of a plumed serpent and an El Paso Polychrome vessel with a plumed serpent painted on its surface from a room in Hot Well pueblo.

Clearly there is much we do not understand concerning rockart and iconography and the information it contains regarding interaction. However, when arguments for interaction are made based on similarity in design styles, careful attention needs to be given to chronological placement and degree of similarity so as to rule out the possibility of coincidental occurrence or independent invention. The larger problem, however, is attaching substantive behavioral meaning to the diffusion of particular iconographies.

Turquoise

In the Jornada region turquoise has been recovered from excavated rooms and from caches (Wooldridge 1979:88). The Jarilla Mountains, located north of the study area at Orogrande, New Mexico, is the closest source with evidence of prehistoric turquoise mining (Carmichael 1986; Mathien 1995). It is likely, although undemonstrated, that much of the turquoise found in the Jornada area derives from the Jarilla Mountain source. However, since turquoise is

known to be a valued trade item its occurrence needs to be reviewed.

Alamogordo Site 2 contained five shaped and polished, undrilled turquoise pendants in a cache beneath the floor of Room 7. They were buried in a small jar along with several *Olivella* shells and a large quartz crystal (Lehmer 1948:62). Whalen (1994) recovered 11 pieces of turquoise and seven calcite beads from excavations at Turquoise Ridge. Calcite has been found in other sites as well (Kelly 1977; Whalen 1987:176; Wooldridge 1979). Most of Whalen's 18 items come from the fill of the supposed ceremonial structure dating to A.D. 820 \pm 60. The chips of turquoise recovered were small or badly flawed, and Whalen presumed these to be manufacturing remnants (1994:128). Whalen (1994:128) notes that the simplest assumption is that many ornamental objects were made at the sites where they were found. "The turquoise waste material from the Turquoise Ridge sites shows that at least some ornament manufacturing took place there. Moreover, there is at least the implication that such activity was more common in the late Formative occupations than in the early part of the period" (1994:128). Other discoveries of turquoise in the area were from caches (Kelly 1977; Moore and Wheat 1951; Wooldridge 1979).

10.2.3.3 Caches

A number of significant caches have been found in the region and need to be evaluated for their potential to yield direct evidence of interregional interaction. Although they occur in many parts of the Southwest, they may be more frequent in the Jornada and Mimbres areas than other regions (Wooldridge 1979:7). Marshall (1973) and Kelly (1977:158) summarized previous caches found in the region, as several have been located and reported while some have been reported but not documented. Phelps (1967; see also Wooldridge 1979) reported on two sites on McGregor Range and undocumented caches in the Hueco Mountains and Villa Ahumada, Chihuahua, Mexico.

Moore and Wheat (1951; see also Wooldridge 1979) reported a cache found in 1936 on the Tobin

Ranch 11.5 miles northeast of El Paso. The cache contained 17 ceramic vessels, of which 76% were Chihuahua wares with one Tucson Polychrome vessel. Shell ornaments recovered from the cache numbered 7,477. Beads described as flat, discoidal, white shell beads numbered 6,029, and 1,431 *Olivella* shell beads were also recovered, as were five nacreous shell pendants, one with a zoomorphic design and four with geometric designs. One fragmentary shell bracelet, 13 other perforated shells and beads were also present. This cache contained 105 unworked, worked, and finished pieces of turquoise along with 12 stone artifacts including large, discoidal, polished stones; stone balls; rectangular, tabular stone objects; and stone beads. There were 11 polished pebbles and chalcedony concretions. The rims of five *ollas* were weathering from the sand matrix in an open area. The *ollas* had roughly circular breaks in the bottoms of the vessels ("killed") while the others apparently were intentionally smashed. One vessel was left complete. Given the ceramic associations, the cache is placed within the El Paso phase time period (A.D. 1250 to 1450).

Kelly (1977) reports on the High Lonesome Bead Cache, located during the archeological survey of the Radium Springs area (Hester 1977) on the western side of the San Andres Mountains in the Jornada del Muerto. The cache was contained in a vessel identified as Alma Punched. There were also Mimbres Boldface Black-on-white sherds associated with the site. The cache was dated to the Mesilla phase and was made up of 871 beads of calcite, shell, and turquoise with some pendants of the same materials (Kelly 1977:141-171). This cache was not thought to be a trader's cache or to have a ceremonial meaning. Kelly notes the cache was buried, marked with a cairn, and that the owner intended to return. The cache is unique in that the beads of varying size were strung biconically in progression from smallest to largest to smallest. Apparently most strung beads reported in the Southwest are cylindrically strung and comparatively constant in size (Kelly 1977:164).

The Bald Eagle Cache, found during the McGregor Guided Missile Range survey in 1976, was located

near the top of a mountain peak in a precipitous overhang in the Sacramento Mountains (Wooldridge 1979). The two cached vessels appeared to be of local origin. Andesite, found in the Sierra Blanca Mountains 80 km to the north, was in the temper of these anomalously shaped vessels (Wooldridge 1979:19). The vessels contained 50,009 artifacts, mostly jewelry. The cache included beads of marine shell, calcite, slate, and turquoise. Pendants were fashioned from turquoise, and marine and freshwater shell (*Lampsilis bracteata*), from the Llano, Guadalupe, and Colorado river system in Central Texas. One of the species of marine shell used in the manufacture of beads was *Spondylus princeps*. This shell is from the Pacific coast of Baja California or the southern Gulf of California coast as far south as Jalisco (see Bradley 1996; Southward 1979). *Glycymeris* shell bracelets as well as spangles, buttons, quartz crystals, a burnishing stone, limonite, and possibly turquoise ground for pigment were also present.

Wooldridge's (1979) analysis of the Bald Eagle Cache was undertaken in an attempt to infer the cultural intent behind the cache's deposition. Wooldridge, finding no published models for understanding caches, developed a research design that included five hypothetical models and test implications for each. The cache interpretations included a shrine, a votive offering, an artisan's repository, an individual's personal possessions, or a trading venture. The Bald Eagle Cache and four other jewelry caches from the Jornada region were evaluated. Two additional caches from the Hohokam area were also included as a comparison. Wooldridge concluded that the Bald Eagle Cache represents a trading venture. But it was also determined that Paquimé was not the manufacturing locale for the cached objects because of distinctive stylistic differences and the ^{14}C date from the cache, even though some of the shell species were also found at Paquimé (Wooldridge 1979:177).

10.2.3.4 Feathers

This group is mentioned here only as it may be possible that faunal remains in caves in the study area could contain macaw remains. Scarlet macaws (*Ara macao*) and/or their feathers were items of production (breeding) and exchange at Casas Grandes (Bradley 1992:127). Two recent archeological projects in Chihuahua indicate that macaw production was not limited to Paquimé. The political relations of production for these ritually and economically important birds differed depending on whether or not the producers were part of the complex polity centered at Paquimé (Minnis et al. 1993:270-276). Two other species of macaw (*Ara militaris*) and parrot (*Rhynchopsitta pachyrhyncha*) probably could have been obtained from closer natural ranges as close as southern Sonora and southern Chihuahua (Creel and McKusick 1994). Feathers, probably the primary macaw product used and traded, are unlikely to withstand the rigors of time and environment. The identification and distribution of macaw bones are used to infer patterns of parrot use and exchange. The only macaw remains identified from the northeastern periphery of Casas Grandes are from sites in the Mimbres region (Creel and McKusick 1994). Those sites predate the Medio period, when Casas Grandes was flourishing. No macaws have been reported from Animas, Black Mountain, or El Paso phase sites (Minnis 1984:183). Minnis does mention that this could be the result of the few detailed analyses of faunal assemblages from sites. Mention of feathers is made in Cosgrove (1947:38) in the context of a "single-pin" hair ornament wrapped with sinew holding fine feather quills. He also mentions a twig wrapped with fiber holding feather quills, in describing an ornament or paho attachment (a ring wrapped with vanes stripped from red feathers). There is also a mention of "blue downy" feathers. Certainly, there is little to go on in the study area, but the likelihood of finding a macaw skeleton in a faunal assemblage in one of the many caves and/or rockshelters in the study area is greater than recovering faunal evidence in the bolson. Interaction with Casas Grandes is undoubtedly in place considering the evidence gathered over the

past 50 years (Minnis 1992). Since other items, such as copper bells and marine shells, have definitely been documented in the area, we cannot by default exclude the possibility of the presence of macaws in archeological contexts in the study area.

10.2.4 Summary of Formative Interaction

10.2.4.1 Mesilla Phase

Evidence for interaction in the study area during the Mesilla phase can be found in the presence of intrusive pottery types and shell. Mimbres Black-on-white pottery, as indicated by recent NAA work was almost certainly made in the Mimbres area. Considering all time periods, Mimbres Classic Black-on-white sherds were the second most common intrusive in the study area (e.g., Carmichael 1986; Smiley 1977), suggesting that one of the highest levels of interaction occurred between ca. 950 and 1150 with the Mimbres area. In addition, other Mogollon types including San Francisco Red, Mogollon Red-on-brown, Alma Plain, and Alma Neck Banded have been found in small quantities, these may have derived from the Mimbres area or elsewhere in the western Mogollon region. Less than five sherds of Red Mesa Black-on-white, a type common to the Little Colorado River region, have been reported from the study area (e.g., Carmichael 1986; Smiley 1977). Beads made from *Glycymeris*, *Pyrene*, and *Olivella* shells from the Gulf Coast of California suggest that at this time the southern Jornada area was linked into a broad-scale movement of shell across much of the eastern Southwest (Bradley 1996).

10.2.4.2 Doña Ana Phase

During the Doña Ana phase, there was an increase in the absolute number of intrusive sherds, an increase in the number of intrusive pottery types, and an increase in the number of regions from which they derived, suggesting that there was a broadening scale of interaction during the ca. A.D. 1100 to 1250 period. Interaction with the Mimbres area and possibly other portions of the Western

Mogollon region continued as reflected by substantial numbers of Mimbres Classic Black-on-white found in deposits dating to the first 50 years of the Doña Ana phase (e.g., Hard et al. 1994). Mimbres ceramics were no longer coming into the area after A.D. 1150, with the cessation of the Classic Mimbres Valley occupation. Interaction with the northern Jornada area and perhaps the Middle Rio Grande is indicated by substantial quantities of the most common intrusive, Chupadero Black-on-white. The existence of San Andres Red on-terracotta and Three Rivers Red-on-terracotta indicates interaction with the northern Jornada area. These redwares occur approximately in the same frequency, tying for third place, with Chihuahuan wares (excluding Playas Red and Ramos Polychrome see below), following Chupadero and Mimbres Black-on-whites.

Wingate Black-on-red and St. John's Polychrome from the eastern section of the Little Colorado River are present in small numbers. Also appearing for the first time during the Doña Ana phase are Playas Red and Ramos Polychrome. These types have been frequently assumed to be Chihuahuan in origin; however, recent compositional analyses tentatively suggested that Playas Red was probably made in multiple locations including both the northern and southern Jornada areas as well as in multiple locations in Chihuahua (Bradley and Hoffer 1985; Creel 1995). Playas Red is the most common of all the "Chihuahuan types" in the study area and is roughly fifth in rank order of occurrence of all "intrusives" for all time periods. For example, at the Hueco Tanks site (Hard et al. 1994; Kegley 1982) dating between 1075 and 1150, Playas Red was the second most common intrusive, behind Chupadero Black-on-white. Note that this is prior to the ca 1200 and 1450 Medio period at Casas Grandes when the town of Paquimé was occupied (Dean and Ravesloot 1993). Playas Red does not appear to be representative of a Casas Grandes interaction, but may represent a shared style that is manufactured in a number of locations across a broad area, including Casas Grandes.

The Ramos Polychrome sherds found in the southern Jornada area have yet to be systematically examined. Both chemical and stylistic studies suggested that the Ramos Polychrome sherds found on Animas sites in southwestern New Mexico were not made at Casas Grandes. Further, the Ramos Polychrome from Casas Grandes had a distribution limit of ca. 80 km (DeAtley and Findlow 1982; Woosley and Olinger 1995). It is likely that the Ramos Polychrome sherds found in the study area were also not made in Chihuahua, leaving open a number of alternative possibilities requiring exploration.

Interaction during the early part of Doña Ana phase was focused on the Mimbres and the northern Jornada areas, perhaps extending to the central Rio Grande. There is no clear evidence of the movement of material objects between Casas Grandes and the study area at this time, although there are certainly common pottery styles being used. The Animas phase occupation of southwestern New Mexico, including the Mimbres Valley, needs to be evaluated as a source of intrusive pottery, including Ramos Polychrome, during the Doña Ana phase (see Lehmer 1948).

10.2.4.3 El Paso Phase

Interaction with outside areas reaches its most active stage during the El Paso phase. Shell ornaments, from the Gulf of California and possibly the Pacific coast of Baja California occurred. The shell styles that were present during the El Paso phase cluster with styles present across a broad portion of the Southwest including Casas Grandes, the Western Pueblo tradition in Arizona, Upper Rio Grande, Salado, and Mogollon regions. The site of Casas Grandes contained millions of pieces of shell and evidence for specialized shell manufacturing. Its role in the distribution of shell is not clear. This cluster is distinct from one containing the Hohokam and Anasazi regions in Arizona and Chaco Canyon (Bradley 1996).

The number of intrusives increased again during the El Paso phase reaching a zenith in interaction considering the absolute numbers of intrusive

sherds, types, and regions represented. Evidence of Interaction with the Three Rivers region in the northern Jornada continued to be present. Lincoln Black-on-red, another Three Rivers redware, was added at this time. Other evidence of interaction with the northern Jornada area, or perhaps the Middle Rio Grande region, is the continued high frequency of Chupadero Black-on-white, the most common intrusive in the El Paso phase. Two new types from this region occurred for the first time as well. Limited interaction with the Western Mogollon continued as indicated by the presence of Seco Corrugated. Continued interaction with the Little Colorado River region is indicated by the continued presence of White Mountain redwares as well as two additional types.

Evidence of interaction with additional regions is also present. By El Paso phase times the evidence for interaction with Casas Grandes is indicated by the presence of small numbers of sherds of Villa Ahumada Polychrome, Carretas Polychrome, Corralitos Textured polychrome and Convento Rubbed Corrugated. These types are present in El Paso phase sites in quantities roughly equivalent to the Three Rivers types. The occupation of the site of Paquime lasted from ca. A.D. 1200 almost to Spanish contact (the Medio period) correlating with the El Paso phase.

Playas Red, and its varieties, were common in the El Paso phase as they were during the Doña Ana phase and may have been manufactured in the Jornada area as well as Casas Grandes. Ramos Polychrome also continued to be present in the El Paso phase and may not have been made at Casas Grandes either. These sherds may have derived from the Animas phase sites in the southern Mimbres Valley and southwestern New Mexico (see Woosley and Olinger 1995).

Evidence of interaction with the northern Rio Grande region occurred for the first time in the El Paso phase with the occurrence of a few sherds of Galisteo Black-on-white, Agua Fria Glaze I, and Arenal Glazed Polychrome (e.g., Carmichael 1986; Lehmer 1948; Smiley 1977). Evidence of interaction with southeastern New Mexico occurred

for the first time in the El Paso phase as a few sherds of Ochoa Brown occur in the study area. Gila Polychrome occurred in small numbers on El Paso phase sites. Gila Polychrome was widely distributed throughout large portions of the Southwest. Crown (1995), as a result of an NAA study, concluded that Gila Polychrome was made at multiple locations in the Roosevelt-Tonto Basin region in central Arizona. Salado Interaction was also indicated by the presence of Tucson Polychrome, a type that was thought to derive from the San Pedro River region in southeastern Arizona (Oppelt 1976).

In summary, the El Paso phase intrusive ceramic data includes evidence of interaction that began in an earlier phase with the northern Jornada area, Middle Rio Grande, Western Mogollon, and Little Colorado region. Evidence of interaction with additional areas during the El Paso phase include northern Chihuahua, southeastern New Mexico, and central and southeastern Arizona. Clearly, El Paso phase society was involved in a greater level of interaction, with more regions than previous occupations (Beckes et al. 1977; Carmichael 1986; Lehmer 1948:81-82; Smiley 1977, Whalen 1977, 1978). However, based on the frequency of intrusive sherds, such as Chupadero Black-on-white and the Three Rivers wares, as an indicator, interaction with areas to the north, particularly the northern Jornada region (and perhaps the Middle Rio Grande), far outweighs interaction with any other region (see Lehmer 1948). Of the remaining regions, intrusives from Casas Grandes are the next most frequent (excluding Ramos Polychrome and Playas Red). Sherds from all other regions are represented by trace amounts.

Figure 39 showing the origin of El Paso phase intrusives and Bradley's (1996) shell stylistic cluster that includes the Casas Grandes, Salado, Western Pueblo, Mogollon, upper Rio Grande regions, and Jornada regions show remarkable similarity. Both indicate that the Jornada region was participating in a broad-scale interaction that connected much of the eastern part of the Southwest. This system was independent of regions further to the west, northwest, and north

including the Hohokam, Sinagua, and Chaco Canyon regions. Based on the frequency of intrusive sherds, shell, and copper bells in the southern Jornada area it appears that the level of interaction with regions beyond the Jornada area was not substantial, including Casas Grandes.

Lehmer (1948) showed that El Paso Polychrome was present as an intrusive over a wide area that is remarkably similar to the shell distribution cluster. It includes the Salado region of central and southern Arizona, the Animas region of southwestern New Mexico, the Mimbres Valley, and the lower Pecos River region in southern New Mexico. Excluded is the Upper Rio Grande and Little Colorado River area. El Paso Polychrome was the second most common intrusive at Casas Grandes.

10.2.5 Conclusions

There is substantial discussion of the potential for trade and exchange of such items as marine shell, turquoise, feathers, and copper bells from around the Southwest. The focus of studies of trade and exchange has tended to be at the regional or extraregional level, such as Chaco Canyon and the Mogollon and Casas Grandes for example. However, as Cordell (1984:283) notes, most of the Southwest between A.D. 900 to 1150 was not incorporated into any of the ongoing regional systems in a direct way. The prevailing pattern was one of continued local development. As an "area in between" (Cordell 1984:300), the Jornada region was still relatively small scale in its community organization (i.e., villages) may have only been a few related families who were still mobile, with hunting and gathering being punctuated by small agricultural pursuits. Thus, in what Dalton (1977:194) refers to as a stateless society, trade and exchange must have been on a personal level. Individuals depended upon their families, lineages or clan affiliations for material livelihood and political security. Items of value or "primitive valuables" were currency against common plights of sporadic hunger, sporadic warfare, and for external trade (Dalton 1977:193). As mentioned in the beginning of this chapter,

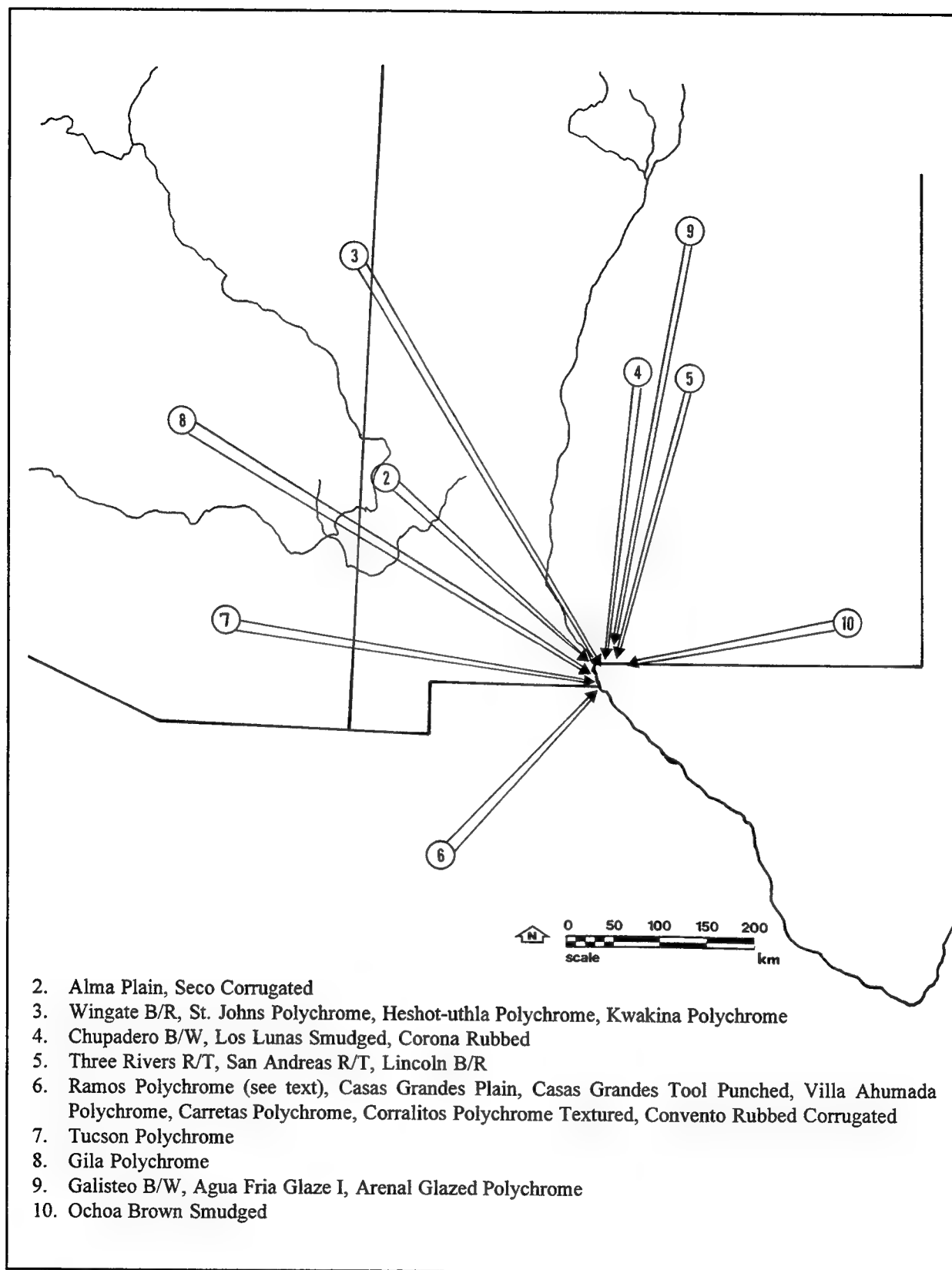


Figure 39 Source Areas of Intrusive Ceramics During the El Paso Phase.

gifts or exchanges often imply obligation on the part of the recipient. This obligation can translate to subsistence needs in times of stress, additional territorial rights, etc. Trading or exchanging ornamental objects are acts of symbolic regulation, maintaining channels through which flow essential utilitarian goods and foodstuffs (Whalen 1987:177).

10.3 RESEARCH QUESTIONS

Questions regarding interaction/exchange/trade focus on materials mainly. Focusing on materials can, however, lead to other levels of inquiry that call for assimilating data on settlement, subsistence, and social organization within the study area, and on intraregional and interregional bases. Generally speaking, are there specific geographic or environmental zones within Fort Bliss boundaries that can be targeted for this research domain?

10.3.1 Ceramics

- 10-1 Can clay/temper sources and local ceramic wares be tracked with sufficient precision to locate sources through time?
- 10-2 Can temporal refinement on intrusive wares such as Mimbres varieties illustrate any cultural lag with regard to trade?
- 10-3 Is there sufficient temporal and quantitative data on ceramics (or can it be generated or acquired?) in the area which would reflect pulses of interaction?
- 10-4 Can directional pulses of interaction be perceived through these analyses?
- 10-5 Are there sufficient differences between east and west sources of clay and/or temper to track intra-area exchange or movement? How can these two (exchange or mobility) be discerned?
- 10-6 Are there local sources of clay/temper that might have been used in making "cognate wares" of intrusive varieties?
- 10-7 Can sourcing be refined on locally made Mimbres wares?
- 10-8 Are there any local sources for Playas Red?
- 10-9 Can local ceramics be sourced by analysis of slips or paints? Can they be dated by such methods?
- 10-10 Can El Paso wares traded out be sourced (e.g., can El Paso Polychromes found in Paquimé be traced to local areas?).
- 10-11 Can more (and which) detailed data clarify the Doña Ana "dilemma"?
- 10-12 Are current ceramic rim indices sufficient to track temporal factors?
- 10-13 Can a continuation of characterization and provenience work on clays (samples over the full range of areas on the Fort) and provenience of El Paso Brownwares shed any light on intra-area exchange or mobility?
- 10-14 Can chemical characterization identify source areas of other intrusives, particularly Ramos Polychrome, other so-called Chihuahuan wares, Gila Polychrome, Chupadero Black-on-white, and others? The chemical characterizations conducted thus far reflect a pattern of multiple locations of manufacture for types previously considered to be intrusives.

10.3.2 Lithics

- 10-15 Is there a particular lithic style indicative of the Jornada? If not, do we know why?

10-16 Are current lithic stylistic parameters sufficient as fair temporal markers for the Jornada? Can (or should) these be refined?

10-17 Can lithic tools be tracked via sourcing/characterization from east to west to indicate either intracommunity or intercommunity exchange or mobility?

10-18 Using lithics, can the difference between mobility and exchange be realized through lithic studies of source and/or context?

10-19 Can sourcing/characterization of obsidian, other lithics, or minerals differentiate between local Rio Grande gravels as source and genuinely "imported" lithics from the north as source?

10-20 How can we get beyond mere presence/absence of lithic materials (like Edwards or Chuska chert) in the area?

10-21 How can we track lithic resources from this area that might be found in other archeological sites outside the region? Can the source database be published and disseminated?

10-22 Where are the lithic procurement sites on Fort Bliss and in the immediate region?

10-23 Can we be precise about procurement areas for each category, such as ground stone or projectile points?

10-24 What can "site furniture," such as ground stone (manos, metates), tell us about mobility? How can we bring more precision to what we already know?

10-25 Have all the known turquoise caches in the area been sourced? Do we have adequate characterization data on the turquoise source in the Jarillas?

10-26 Can calcite beads, like those found in the Bald Eagle Cache, be sourced beyond the general area?

10-27 Are there manufacturing areas for turquoise in the area (as suggested by Whalen 1994)?

10.3.3 Ornamental Objects

10-28 Have the copper bells found in the area been analyzed? Were they found on Fort Bliss lands? If not, can that, or should that analysis be accomplished?

10-29 Cosgrove (1947) mentions feathers' have any faunal remains of any birds been found in any of the caves or rockshelters on Fort Bliss lands? If so, have they been analyzed?

10-30 What spheres of influence or directions of interaction are involved? Given the temporal factors, could this occurrence (use) of feathers, etc., be from the Mimbres direction instead of Paquimé?

10-31 Can other sources of interaction with the south be targeted on Fort Bliss?

10-32 Can other sources of interaction with the north, west, and east be targeted on Fort Bliss?

10.3.4 Caches

10-33 Specifically, caches are a unique opportunity to view exchange at different levels of interaction. Have all the caches on Fort Bliss been analyzed and characterized?

10-34 Given the advancement in characterization techniques and methodologies over the last ten years or more, would it be feasible to reassess those caches or other artifacts in light of these possible advancements or refinement of techniques?

10-35 Has the research design in Wooldridge (1979) been attempted on other data (i.e., other caches)? Can it be retrofitted to other data concerning trade or interaction?

10.4 DATA NEEDS

In order to continue processing information regarding interaction during the Paleoindian and Archaic periods, a stronger database is necessary. To this end, more survey and inventory should be completed on those portions of the Fort that have had less coverage (e.g., McGregor Range, including Otero Mesa and the Sacramento mountains). Similarly, inventory of caves and rock art should continue. The lithic source survey should be an ongoing project with requirements for immediate integration of newly acquired data. A suite of appropriate methodologies to deal with characterization and source studies of different types of artifacts should be undertaken if not already in progress. Finally, more excavations of different site types in different environmental zones need to be accomplished, and excavations aimed at different scales of analysis should be undertaken.

PART III: SUMMARY

11.0 IMPLEMENTING THE RESEARCH DESIGN

Nick Trierweiler, James Abbott, and Raymond Mauldin

As has been discussed above in Chapter 1.0, the purpose of this research design has been to broadly identify aspects of the Fort Bliss archeological record that are of scientific interest, and then to detail the types of data necessary to pursue those lines of inquiry. It is important to note that these scientific issues exist independently and without regard to the needs of cultural resource management, although they are necessarily applied to management issues.

By and large, the research design has eschewed suggesting particular policies or specific procedures with which to reconcile scientific interests with management needs. Developing these mechanisms, which apply the research needs as significance standards, is the role of a HPP or a CRMP. Such plans are intended to balance the scientific goals with the practicalities of managing non-renewable cultural resources. At Fort Bliss, such balancing requires resource managers to make tough decisions on how to allocate limited personnel and budgets so that the primary mission of the fort - maintaining military readiness - is not compromised, while simultaneously minimizing adverse impacts to the archeological record.

At its core, the research framework has consisted of:

- (1) identification of a set of important regional archeological issues which are currently poorly understood and which merit future research;
- (2) identification of currently feasible approaches to pursue those issues; and
- (3) enumeration of the data requirements necessary to satisfactorily address the issues.

We have intended to design a research framework which will permit significance evaluations for both known and undiscovered archeological sites. From a management perspective, two sets of archeological resources exist at Fort Bliss: (1) sites already on record as a result of previous inventories; and (2) sites not yet discovered. A subset of the first category consists of previously recorded archeological phenomena which, due to changing methodologies and definitions, were never formally designated as "sites." Depending on which of the many previous inventory projects are accepted as adequate, approximately 30 to 40% of the fort has been archeologically surveyed, resulting in the identification of about 13,400 prehistoric sites. Because this sample is heavily skewed towards the Bolson, this sample is probably not representative of all of Fort Bliss, and moreover is to some extent an artifact of the procedures and site definitions used during the previous surveys. Nonetheless, simple extrapolation of these data suggests that there may be as many as 15,000 to 30,000 additional sites not yet documented in the uninventoried areas. In this chapter, individual sections separately discuss applying the research design to these different data sets.

11.1 THE RESEARCH DESIGN AS A TOOL

It must be emphasized that the research design is merely a tool used to obtain a measure of significance. Alone, it can not be used as a determinant of NRHP eligibility. For this purpose, the necessary complement to the research design is the CRMP. This is to say, while a research design may identify artifact type *X* as a data set needed to further our scientific understanding, it is the CRMP which must calibrate the value of a single *X* artifact (or hundreds of *X* artifacts) in terms of significance and NRHP eligibility.

To use a simple analogy, consider a process intended to determine whether several pools of water are safe for children. There might be a number of criteria used to determine danger such

as depth, temperature, or the presence of sharp rocks or alligators. In this scenario, the "research design" would review children's health and safety issues, would identify criteria, and would specify the tools needed to assess them, such as a meterstick, a thermometer, or a tally sheet. By contrast, the CRMP would assess the "need" for the children to go swimming, would set the boundaries of what constitutes safety, and would balance these into a set of policies and procedures such as: children under seven may only swim in water shallower than 1.2 m; or, no one may swim if any alligators are present.

It is axiomatic that all archeological sites have some data content, and thus some inherent research value. Nevertheless, federal laws provide for preservation of archeological sites only if they meet explicit significance criteria. Any sites which do not meet those criteria are not subject to protection. There are no shades of gray provided by the law; each site is either significant and worthy of protection, or is not significant and is not afforded protection. Typically, the most intensive process in CRM is the initial cycle where a site is identified and evaluated for significance. During this process, which can frequently take years for large inventories of sites, each site is assumed to be potentially significant, and is afforded protection, until such time that lack of significance can be demonstrated. Thus, the "burden of proof" favors the unevaluated archeological resource.

One of the paradoxes of cultural resource management is that the state of knowledge is in constant flux, and any research design is by definition a document with a limited life-span. At the same time, a research design forms the basis of significance decisions that affect management of that site, which has lasting implications. Although future innovations in archeological techniques and shifts in basic theoretical paradigms or research strategies have the potential to alter significance criteria considerably, the law does not allow for site protection unless it meets current data requirements. However, it is acknowledged that theoretical changes may occasionally require re-

evaluation of sites on which a prior determination has been made under revised requirements.

11.2 EXISTING SITE DATABASE

More than 13,400 prehistoric archeological sites are already in the Fort Bliss inventory. Several fundamental problems exist with this site database, primarily as functions of the various procedures used during previous pedestrian surveys. This section addresses the challenges of using the extant database to evaluate site significance.

11.2.1 Methodological Biases

This section reviews the effects of changes in survey methodologies on the number, density, average size, and diversity of sites recorded on Fort Bliss. The Fort Bliss Site File computerized database has developed out of archeological work on the post over the past 20 years and includes a variety of data on approximately 13,400 archeological sites. Because of changes in site definitions and recording procedures, about 11,000 sites may have usable information, and this database has been used in the methodological analyses in this chapter.

As we discuss below, site size can be a critical variable in determining overall data content within a site, including the number of artifacts and features, the number of different artifact types, and the number of temporal components identified. These variables are important not only for interpretive constructs, but also are used to assess the research significance of a site. However, using a variety of survey projects conducted in the region, it has been argued that survey methodology can strongly influence the average recorded size of sites (see Mauldin 1995, Mauldin, Graves, and Bentley 1994, Ansheutz 1990). This means that, in combination with geomorphic processes, different survey methodologies have the potential to influence the apparent data content of a site, and by extension, its overall research potential.

Survey Intensity and Site Density

One of the first extensive surveys within the Fort Bliss Maneuver areas was conducted by Whalen (1977; 1978). These studies were conducted only three years after the 3rd Armored Cavalry first came to Fort Bliss, and subsequent surveys may have recorded more sites per unit area simply because of increased erosion. Whalen's survey in Maneuver Area 2 used variable transect spacings between 20 and 60 m, depending on terrain and archeological material (Whalen 1977:12). The subsequent survey in Maneuver Area 1 (Whalen 1978) used a transect spacing of roughly 46 m (Carmichael 1986a). Several years later, a survey of Maneuver Areas 3 through 8 used transect spacing of 33 m between crew members (Carmichael 1986a:24).

The effect of these changes in survey intensity is illustrated in Figure 40 which compares overall site density for six survey projects at Fort Bliss. Grouping the surveys into two classes (corresponding to small and large transect intervals), the figure suggests that more sites are discovered as survey intensity increases. Although all six projects were conducted in the Hueco Bolson and crosscut similar land forms, they were conducted over a period of years, during which increased erosion resulting from tracked vehicle maneuvers may have served to expose sites which would have otherwise remain hidden.

Changes in Site Definitions

While no explicit site definitions have been located for the initial surveys of Maneuver Areas 1 and 2, the surveys of Maneuver Areas 3-8 defined a site as any cultural feature or a minimum of ten artifacts within a 30 m radius (Carmichael 1986a:24). Features were defined as at least ten rocks within 16 m² (Carmichael 1986a:25). About 34,000 manifestations that did not qualify as sites were assigned to a "limited scatter" class, and about one-quarter of these had burned rock present, but at densities which did not meet the site criteria.

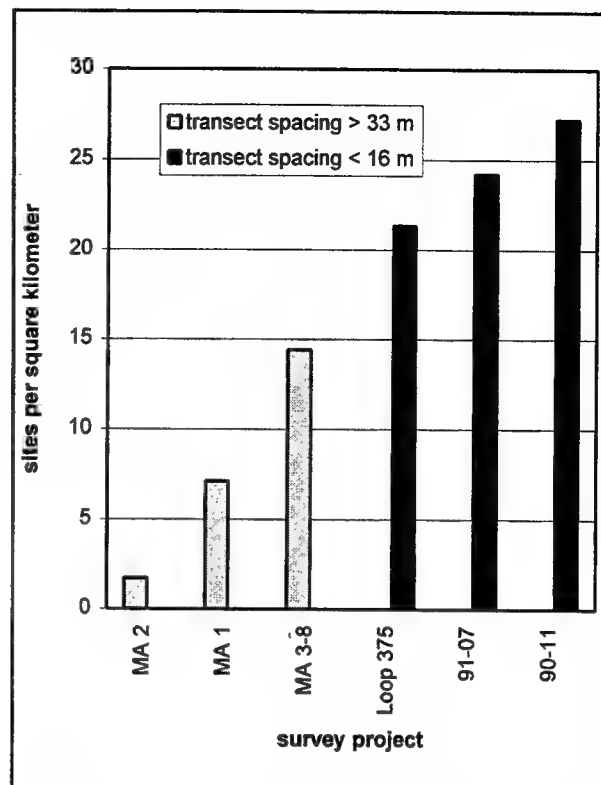


Figure 40 Comparison of Survey Intensity for Six Fort Bliss Survey Projects.

In the late 1980s, a standard site definition and standardized kinds of observations on sites were initiated for survey on Fort Bliss. The site definition was formalized as three different artifact types, or three different material types, within a 15 m radius, or the presence of a feature. Because of the variable recording procedures used during the earlier surveys, an effort was initiated to standardize the database. Termed Project 90-05, this study relied on survey notes and aerial photos to reassess and standardize previous survey data. New sites were defined in Maneuver Areas 1 and 2 (Lukowski, personal communication, 1995) in an effort to make these earliest surveys more comparable to the more recent surveys, but the "limited scatter" data from Maneuver Areas 3-8 were not included and no new sites were defined in these areas. Nonetheless, because of the changes in methodology and the inconsistencies in survey procedures, the actual number of sites on the Fort Bliss Maneuver Areas may be greater than currently reflected in the Site File database.

Survey Intensity and Site Size

In addition to affecting the overall frequency and the density of recorded sites, several studies of Fort Bliss data (Mauldin 1995; Mauldin, Graves, and Bentley 1994; Leach 1994) also suggest that increasing survey intensity also changes average site size. Using data from Fort Bliss Project 90-11, Mauldin, Graves, and Bentley (1994) presents the results of repeated surveys of the same 1 x 2 km area, but at variable survey intensity. The initial survey of the area, conducted in 1977 by Whalen (1978), used 46 m spacing between crew members (see Carmichael 1986a). The resurveys were conducted at 33 m and 16 m between crew. The final survey pattern (1 m) is actually the result of intensive surface collection. The data suggest that at low survey intensities (46 and 33 m spacing), small sites dominate the survey block. Increasing survey intensity results in larger and larger sites until, at 1 m, much of the eastern edge of the 1 x 2 km area could be considered to be a single site. Details of the initial survey procedures conducted at 46 m are unclear; moreover, these surveys were conducted before the extensive erosion caused by tracked vehicle maneuvers. However, the 33 and 16 m surveys and the 1 m surface collections were conducted within a six month period using the same crew, recording procedures, and site definitions.

These studies argue that survey methodologies can determine to a large degree both the number of sites and their general size range. As survey intensity increases, more sites are discovered, and these sites tend to be larger in size. As we discuss further below, the number of sites and site size are elements which must be considered in any successful application of this research design.

11.2.2 Geomorphic Biases

The survey database biases, both in the variable site definitions and the impact of differential survey intensity on site number and site size, result primarily from modern decisions made by previous researchers on Fort Bliss. By determining not only what constitutes a site, but also how sites will be

searched for, previous researchers have introduced a certain level of distortion into the record. This distortion, however, is built upon initial biases created by geomorphic conditions. These geomorphic conditions, related chiefly to patterns of deposition and erosion, both open and close geomorphic "windows" into the archeological material. In other words, we suggest that within the Fort Bliss study area geomorphic processes are fundamental elements in determining the patterns that archeologists observe and record as sites.

For example, patterns of sand deposited in dunes and ridges and interdunal blowouts determine where the boundaries of sites have been drawn. Site boundaries influence the basic data content of a site by influencing the number of artifacts, the number of different types of artifacts, the number of features, and the number of different temporal components represented. Geomorphic processes also impact assemblage composition on a site by differentially distributing archeological material on the surface relative to subsurface. These processes seem to be based largely on artifact size, and are not well understood at present, but may operate differently in distinct geomorphic settings (see Chapter 5.0; Mauldin 1995; Leach et al. 1994; Mauldin, Graves, and Bentley 1994, Mauldin, Leach and Monger 1994).

Currently, the Fort Bliss site file database lacks any detailed information on the geomorphic contexts for all sites. However, Mauldin (1995; see also Mauldin, Graves, and Bentley 1994; Leach et al. 1994) used a relatively simple distinction based on the dominance of mesquite (which is recorded in the database) to consider general patterns on Fort Bliss. He argued that sites that have mesquite as the primary vegetation are probably locations where dunes and interdunal blowouts are frequent while sites located in settings where mesquite is not the dominant vegetation probably are characterized by little or no erosion (see Gile 1966a; Monger 1993a:35-38; Wright 1960; York and Dick-Peddie 1969). Using over 9,800 sites recorded on Fort Bliss and considering site size relative to this vegetation distinction (mesquite/non-mesquite), Mauldin (1995)

demonstrates that sites located in areas in which the primary modern vegetation is mesquite are considerably smaller (median = 100 m²) than sites in which the primary vegetation is not mesquite (median = 600 m²).

The association between site size and modern vegetation could be the result of site location. Most of the larger sites are located along the base of alluvial fans, settings dominated by non-mesquite vegetation and rainfall runoff. The smaller sites are often in the central basin, settings dominated by mesquite. Such a position has been suggested by a variety of authors (e.g., Whalen 1977, 1978). Under that explanation, the presence of runoff from the fans accounts for these large site concentrations and reflects prehistoric decisions about where to locate "residential villages" relative to "small camps." However, Mauldin (1995) also demonstrates that the same pattern of site size and vegetation occurs within each land form. Sites along the fans which are dominated by mesquite are significantly smaller (median = 400 m²) than sites dominated by non-mesquite vegetation (median = 1,000 m²) settings. The same pattern holds within the Central Basin where mesquite dominated areas have smaller site sizes (median <100 m²) than non-mesquite settings (median = 400 m²). The site size patterns, then, are related to modern vegetation which probably track the degree of recent erosion and deposition.

Recent landscape mapping by Monger (1993c) further clarifies the site size and geomorphic relationship. Monger mapped a series of eolian "soil alteration" units in the central portion of Fort Bliss that are related to patterns of erosion and deposition. Mapping Unit 1 is characterized by deflation as evidenced by the occurrence of lag deposits on the surface, exposed caliche, and dunes of various sizes. Mapping Unit 2 is comprised of dunes and interdunal sheet sands. Mapping Units 3 and 4 are characterized by depositional areas or areas with little or no evidence for erosion (Monger 1993c). Mapping Unit 2 covers most of the central basin zone, while mapping Units 1, 3 and 4 are more restricted.

Almost 8,000 sites occur within the area mapped by Monger (Leach et al. 1994). Using site locations from Fort Bliss, Leach et al. (1994) consider site size relative to these mapping units. For that investigation, mapping Units 3 and 4 were combined to form a low erosional category, Unit 2 comprised a moderate erosional category, and Unit 1 represented high erosional levels. Using their data, the average site size for sites that are in the high erosion geomorphic zone (Unit 1) is 906 m² (n=218). This figure compares to an average site size of 1,536 m² for those sites in the moderate erosion class (n=7,247), and 3,134 m² for those in the low erosion areas (n=458). Therefore, site size appears to pattern with geomorphological units. Leach et al. (1994; see also Mauldin 1995; Linse 1993) argue that as erosion, and the accompanying deposition occurs, distributions of artifacts are divided into smaller and smaller packages. When erosion is low (Mapping Units 3 and 4) blowouts, dunes, and sheet sands are seldom present. When erosion is high or moderate, situations characterized by Units 1 and 2, sand is removed from the surface and deposited into mesquite stabilized dunes and sand ridges. In the later situation, artifacts are lagged into the eroded area, and the dunes and sand ridges created by erosion separates the artifact concentrations into a series of "small sites." Site size, then, is related to geomorphic processes. Figure 41 explores the implications of erosion and deposition in more detail using point provenienced artifacts within a 10 ha area collected during Project 90-11 (Mauldin, Graves, and Bentley 1994; Mauldin 1995). Project personnel subdivided the 10 ha area into two exposure categories: "exposed" areas consisted of blowouts with a small vernier of sand overlaying a compact, caliche substrate, and "built-up" areas comprised primarily of sand dunes and sand ridges (see Mauldin, Graves, and Bentley 1994). Three elements are of interest in Figure 12.3. First, the pattern of exposure follows a west/southwest to east/northeast direction, the direction of the high intensity spring winds in the region. Second, most artifacts occur either in exposed areas or on the margin of such areas. Artifact density in exposed setting is four times as high per square meter than in the built-up area.

Finally, note that while several of the concentrations of artifacts present in Figure 41 would, depending on the survey intensity (i.e., crew transect spacing) and site definition, be identified as "sites," the boundaries would be greatly influenced by the patterns of erosion and deposition, a pattern which is likely produced by spring winds exposing and burying artifacts. Excavation data within the 10 ha block further supports this pattern, as artifact densities are significantly higher under the built-up areas than below the exposed areas (Mauldin, Graves, and Bentley 1994). While a variety of boundaries can be drawn, those site boundaries, and the number of artifacts included within a site as a result of those boundaries, are primarily a function of geomorphic patterns rather than directly informing us about prehistoric activities.

11.2.3 The Relationship Between Site Size and Data Content

The previous sections have suggested that even using extant data, the number of sites within inventoried parcels at Fort Bliss may significantly exceed the number currently recorded in the site file database. Secondly, we have suggested that site size in the study area is significantly influenced by geomorphic processes and survey intensity. This section links these observations, especially those related to site size, with site data content. We demonstrate that larger sites, by virtue of the fact that they encompass more area, contain more artifacts and features relative to small sites. As a function of this larger sample size, these larger sites have a higher probability of containing temporally or functionally diagnostic artifacts and a greater variety of artifact types. That is, the data content of these larger sites is apparently greater than small sites, purely as a function of their larger overall assemblage size.

Many of the research domains discussed in previous chapters of this document are necessarily focused on site level data. One implication of that focus, and of the mechanics of the Section 106 evaluation process, is that sites which have a higher data content will be assigned a greater

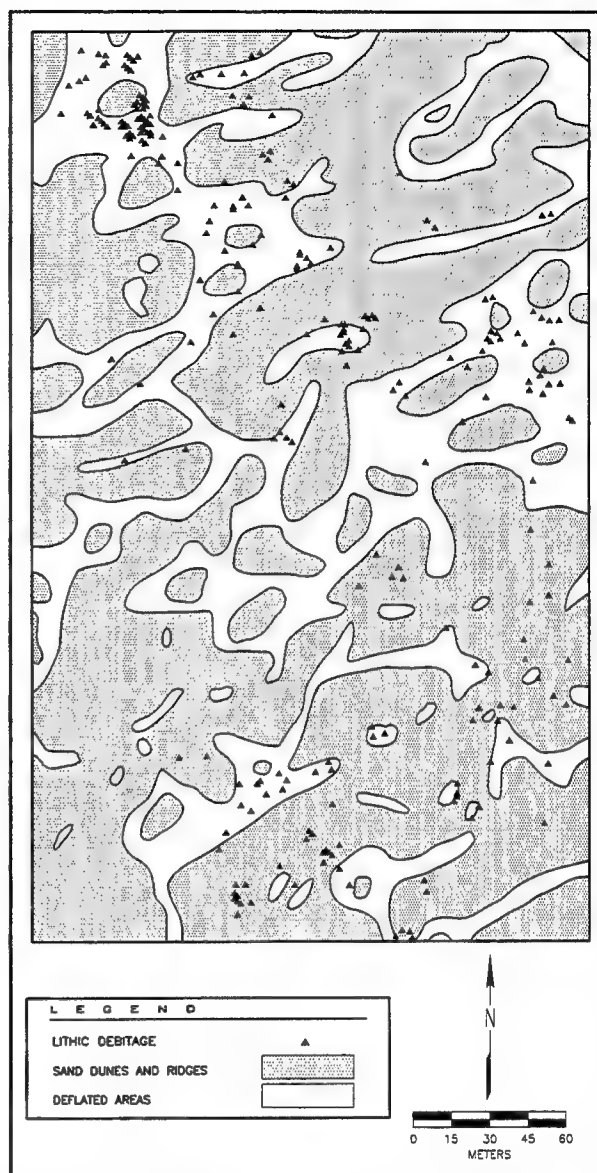


Figure 41 Distribution of Point Provenienced Artifacts Within a 10 HA Area, by Exposure.

research potential. Under conditions of limited time and financial resources, if the site level data content was directly informing us about past cultural systems, such a focus may be appropriate. However, if the data content of a site is a function of site size, (itself a function of geomorphic history filtered through tactical decisions on site definition and survey intensity) then such an approach would not be appropriate for developing either a description or explanation of past cultural systems.

This is especially the case in the Fort Bliss area, where geomorphic patterns are significantly different at a landform level and where survey intensity has been variable over time.

In order to document links between site size, assemblage size, and data content (i.e., artifact variety, feature variety, the number of temporal components), we rely on three data sets. The first is information taken from the Fort Bliss Site File database and summarized by Mauldin (1995; Mauldin, Leach, and Monger 1994). In addition, project specific databases from Fort Bliss Project 90-11 (Mauldin et. al. 1994a) and Project 91-07 (Leach 1993; Leach et al. 1994) are used.

Table 16 presents artifact variety data for all sites in the Fort Bliss site file database with sufficient information. The various artifact types include cores, debitage, informal tools, formal tools, Mimbres ceramics, Chupadero Black-on-white and Chihuahuan ceramics, El Paso Bichrome and El Paso Polychrome, Unspecified Brownware, El Paso Brownware, manos, metates, and other groundstone. Site having zero artifact types were defined on the basis of exposed features. Clearly, the number of types is related to mean site size. The data are graphically presented in Figure 42, using a logarithmic scale. Similar trends are observed for other indices of site area (median, lower quartile, upper quartile). Simply put, larger sites have a greater variety of artifact types. Although the separate itemization of ceramic wares correlates to some degree with the ceramic period habitation pueblos (which tend to be larger anyway), the trend is generally a simple function of more artifacts being included within larger site boundaries (see Leach et al. 1994).

The Fort Bliss Site File database can be similarly used to examine the relationship between number of temporal components and site size. Temporal components are identified by "diagnostic" artifacts (e.g., ceramic types or projectile points) following traditional phase patterns (see Chapters 3.0 and 4.0). Table 17 adapted from Mauldin (1995), clearly demonstrates that the number of temporal components is directly related to site size. Those

Table 16 Number of Artifact Types as a Function of Site Size.

| Number of Artifact Types | Number of Sites | Mean Site Size (m ²) |
|--------------------------|-----------------|----------------------------------|
| 0 | 3,535 | 148 |
| 1 | 2,080 | 600 |
| 2 | 1,712 | 1,944 |
| 3 | 1,270 | 2,828 |
| 4 | 756 | 5,274 |
| 5 | 497 | 6,738 |
| 6 | 331 | 19,536 |
| 7 | 248 | 18,580 |
| 8 | 181 | 41,240 |
| 9 | 93 | 48,331 |
| 10 | 61 | 69,653 |
| 11 | 40 | 96,493 |
| 12 | 13 | 94,308 |

sites without diagnostics are smallest, while sites with artifacts representing only a single temporal period are somewhat larger and sites with more than one temporal period are much larger. The relationship between site size and the number of temporal components is probably a relationship between site size, the number of artifacts, the number of different types of artifacts, and the recovery of artifacts which are "temporally diagnostic." That is, the temporal pattern is significantly influenced by site size. This pattern is probably a function of the low number of diagnostic artifacts (painted ceramics, projectile points) in any assemblage. On any given site, these artifacts usually comprise less than 5% of the total assemblage. As a distribution gets broken up into smaller packages by erosion and deposition, most of these smaller packages lack diagnostics simply as a function of the low overall number of artifacts in the population represented at these smaller sites.

Given the relationships documented above, we would expect site area to pattern with the number of artifacts present on a site. There are no data on the number of artifacts on a site in the Fort Bliss

site file, but data from both Project 90-11 and Project 91-07 demonstrate strong relationships between the size of sites and the number of artifacts. Using 89 sites, Mauldin and Graves (1991) demonstrate a positive relationship between increasing site area and numbers of artifacts. On Project 91-07, a correlation coefficient of 0.76 ($p < 0.001$) between site area and artifact numbers is present for 336 sites with data (see Mauldin and Leach 1994a; Leach et al. 1994). Larger sites generally have larger artifact assemblages. The same pattern holds with the number of features and site area (see Leach et al. 1994; Mauldin and Graves 1991).

As suggested in Figure 43, there are a variety of cultural, processual, and methodological factors which affect the archeological variables of site size, assemblage size, artifact variety, and the frequency of temporal components. These relationships have been documented in the Fort Bliss survey database as a whole, in the central basin relative to erosional units as defined by Monger (1993a), and in several project specific databases. Site size appears to determine a variety of assemblage level patterns, and site size is related to patterns of erosion and deposition, as well as survey intensity. These relationships are probably a function of sample size. As the size of sites increases, more artifacts and features are encompassed within site boundaries. This produces a greater variety of artifact and feature types (see Jones et al. 1983; Kintigh 1989; Leonard and Jones 1989; McCartney and Glass 1990; Rhode 1988, for discussions of sample size/variety issues). Larger sites, primarily as a function of their greater size, have a larger variety of data present. However, this is not necessarily a direct function of variability in prehistoric use of the area. Rather, the underlying patterns of prehistoric use are clouded by geomorphic and survey biases.

11.2.4 Implications of the Biases

The implications for the existing database of the biases outlined above are simply stated.

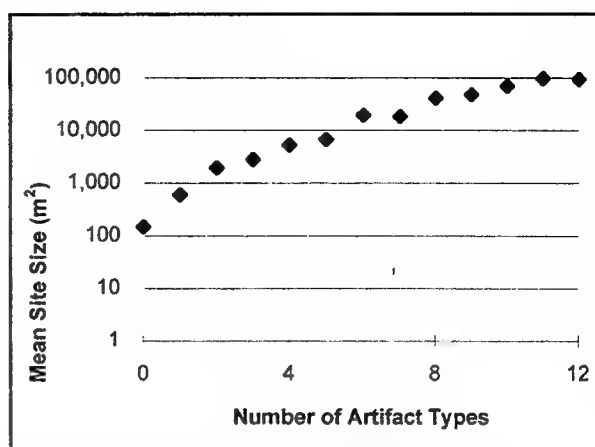


Figure 42 Site Area and Artifact Diversity.

- The existing Fort Bliss archeological site inventory is currently biased by (1) landscape context, (2) the variety of inventory methods used at different times, and (3) incomplete survey coverage. For this reason, the distribution of sites and survey-derived variables such as site size and data content are unreliable, and should not be used for rigorous regional analyses and management decisions. However, the inventory does form the basis for re-evaluation using appropriate and consistent significance criteria.
- The data content on record for individual sites, where determined solely from surface examination, is a function of (1) the empirical data content, (2) broad geomorphic biases, and (3) deep methodological biases. Methodological

Table 17 Number of Temporal Components and Site Size.

| Number of Identified Temporal Components | Number of Sites | Mean Site Size (m²) |
|--|-----------------|---------------------|
| none | 9,072 | 1,658 |
| one | 1,443 | 12,736 |
| two or more | 309 | 48,789 |

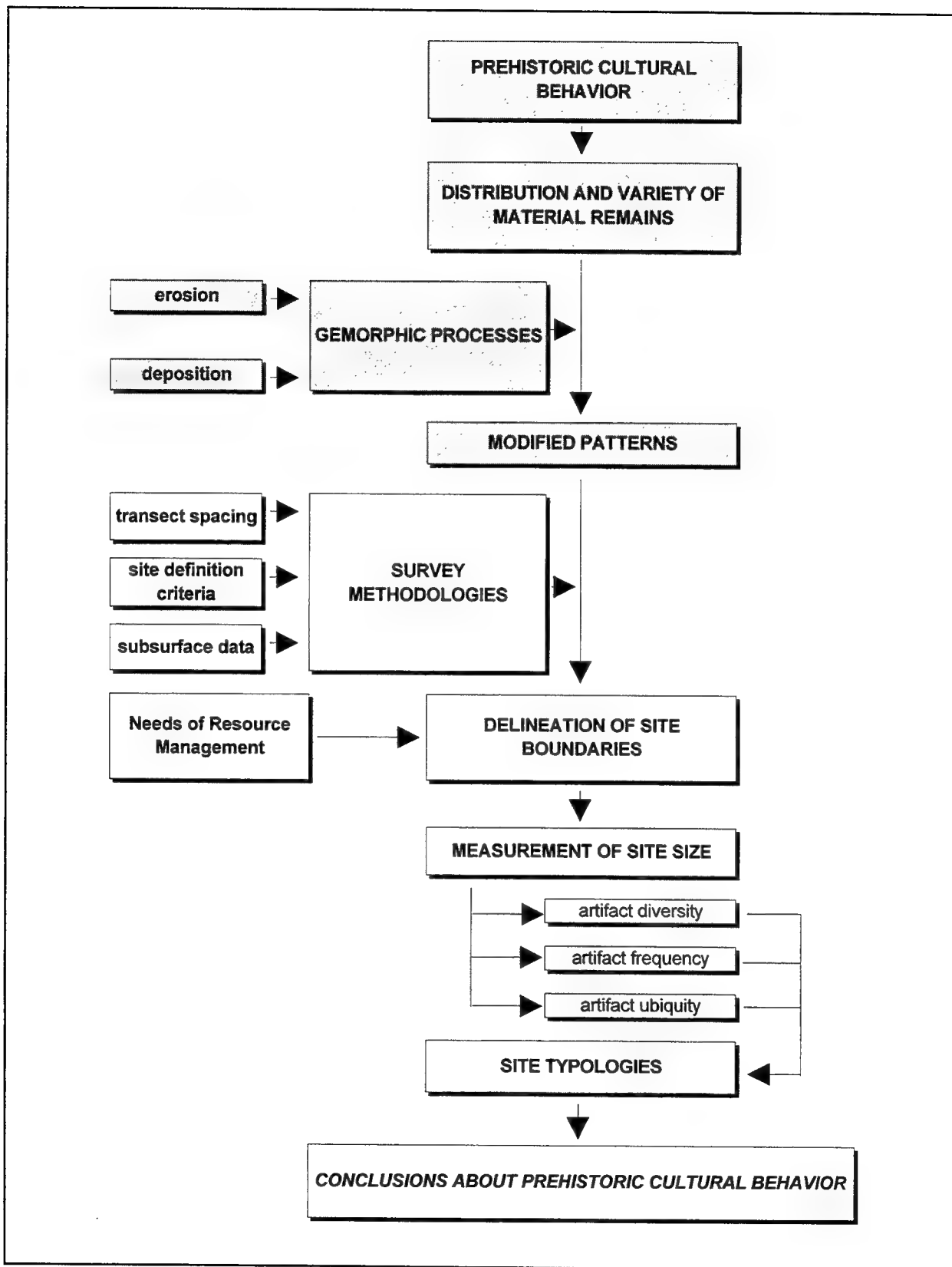


Figure 43 Cultural, Processual, and Methodological Factors Affecting Archeological Data Sets.

biases can be overcome by revisits to sites which replicably evaluate potential according to the data needs specified in Chapters 4.0 through 10.0. Geomorphic biases cannot be entirely overcome by any methodology, but it is possible to minimize these through subsurface examination of the site.

- Therefore, for reasons detailed above in this chapter and in Chapter 5.0, surficial examination alone is arguably inadequate to make an informed decision on data content (and by extension, NRHP eligibility) of sites in many landscape settings on Fort Bliss. This is particularly true of sites situated in eolian environments, on distal alluvial fans, and in the vicinity of fan-channel arroyos; it is also true of many sites in proximal to medial fan settings, playa margins, and colluvial slope settings.

Implementation of a site evaluation program involves many trade-offs. On one hand, a program of surficial evaluations by a knowledgeable team composed of an archeologist and a geomorphologist is better than nothing; it would allow better characterization of the surface manifestation and a specific estimate of the likelihood and magnitude of geomorphic bias. The primary advantage of this strategy of evaluation is that it could be conducted relatively rapidly and inexpensively in comparison to the alternative. However, as the recommendations in Chapter 5.0 suggest, a more involved approach may be preferable in the long run, in which site evaluations would be conducted with the assistance of a backhoe to provide exposures for examination by a geoarcheologist. While subsurface exposures may not be necessary on all site, such trenching on a judicious sample of sites (including a variety of site types in various landforms) would likely provide key information and which to evaluate the overall context and potential for intact deposits. For example, a well placed trench (albeit destructive in nature) could quickly and definitively differentiate between the several

models of site creation and exposure we have discussed in Chapter 5.0. Although such a program would admittedly be much slower, it may well be the only option for adequate assessment of site potential, particularly in eolian contexts. Accordingly, the data collection suggestions and the field forms presented herein are structured to accommodate such an approach.

In either case, the magnitude of the task is staggering. Even discounting any additions to the database from new surveys, which may well occur (particularly if portions of McGregor Range are to be opened to maneuvering), field re-assessment of the surface of only the known sites could take more than 28 person-years. At a rate of three sites per day (an optimistic rate for simple surface assessment) by three matched teams for five days per week and 52 weeks per year, this task could take approximately five calendar years. If mechanically assisted subsurface inspections are employed, then the rate of assessment would be dramatically lower; given an optimistic assumed rate of one site per day by each of three teams, such an assessment would take around 14 calendar years (85 person-years). Moreover, this figure does not account for the time necessary to analyze and report the data, which can conservatively be estimated to take two hours for each hour of field time. Thus, the time estimates, and their associated budgets, can be seen to spiral rapidly.

11.3 STRATEGIC APPROACHES FOR MANAGING THE FORT BLISS SITE INVENTORY

If time and costs are constraining factors in the Fort Bliss CRM program, then there may be only one reasonable solution to the problem, and this is a solution that has a long (albeit controversial) history in archeology: probability sampling.

In essence, everything that archeologists do involves sampling; sites are rarely excavated in their entirety, no site in a given region is ever fully investigated, and regions themselves are studied in vastly differing levels of detail. In a real sense, the sum total of the archeological record is the

only population of interest; that portion of the record that has thus far been examined through archeological investigation is a sample of this whole resulting from the cumulative and conscious decisions about what to investigate made by every archeologist since the founding of the discipline, and forms the only basis we have for making statements about the past. At an even broader scale, the sum of the extant archeological record is itself a sample of all the physical detritus produced by people through time, and the sampling mechanism the vagaries of preservation.

Probability sampling, which grew to wide acceptance as a consequence of the "New Archeology" (e.g., Vescelius 1960; Binford 1964), represents a recognition that sampling, in one form or another, is inherent in archeology, and that adoption of explicit sampling procedures can allow one to make probability statements about the degree to which the sample reflects the population. The concept of probability sampling is predicated on the idea of data redundancy; that is, that different sites formed through similar behavioral and natural processes should contain similar information. Thus, archeological research in a given region should experience a phenomenon of diminishing returns; as more and more sites are investigated, the amount of new information per unit of effort should decline. However, archeology is not physics, and no two sites will ever have exactly the same data content. Thus, no matter how carefully reasoned the sampling strategy, the possibility that unique and important information will be missed is very real. It can be argued, however, that the explicit consideration of the problems involved required to implement probability sampling can only make the arguments advanced more robust, because the problems are there, whether acknowledged or not.

Adoption of sampling as a tool in cultural resource management is permitted under the Section 106 process and related regulations, and is made particularly explicit in the Secretary of the Interior's Standards and Guidelines for Archeology and Historic Preservation. Carefully considered sampling of the existing large Fort Bliss site

inventory for purposes of assessing all resources under Section 106 may be the only viable compliance strategy.

Assuming that the concept of sampling is accepted, a number of decisions must be made to implement it as an effective strategy, whether it is applied to previously documented sites or to unsurveyed areas. The first is the level of effort involved, or a selection of a sample size to effectively represent the population. There are sound statistical methodologies to arrive at such an estimate from initial samples (e.g., Nance 1983; Shennan 1988) provided that the measured parameters are simple; however characterization of the range of variation inherent in a population composed of diverse sites representing a range of time periods and cultural traditions is exceedingly difficult. One possible practical approach is to let the law of diminishing returns dictate the final sample size; that is, continue sampling until data redundancy can be conclusively demonstrated. As suggested by the time estimates presented in the previous section, this approach would itself not be a trivial undertaking in terms of time or budget. However, it would be possible to identify a priori a theoretical maximum sample size necessary to characterize the population (say, conservatively, 50% of the identified sites) and, following identification of the sampling units, immediately release the remaining sites from consideration.

Choice of a sampling strategy is another major relevant decision. Although simple random sampling could be used, the best solution is probably one of two basic stratified sampling options. First, some type of stratification by landform, which would consider samples drawn from subpopulations defined by landscape context, is probably the best solution to address the types of scientific concerns that are the focus of this document. This approach is best compatible with an ecological approach to prehistory, because if the strata were carefully selected it would insure that representative sites from all contexts were addressed with equal emphasis.

An alternative strategy would be to stratify the landscape by intensity of military impact (or some other measure of threat to existing resources). This could allow for (1) focusing on retrieval of information from sites most likely to experience future degradation, and/or (2) exclusion of sites in areas where severe erosion or existing military impacts are documented, such that individual sites in the area can be assumed a priori to have already experienced serious or fatal damage. While generally less attuned to addressing the range of scientific questions posed in this document, such an approach would be better suited to pressing management concerns.

Finally, it is possible that the landscape could be stratified using both of the above criteria, resulting in a two-tier hierarchy of landforms stratified by impact or threat of impact. This approach is one method of partially rectifying the disparity of goals implicit in scientific and management concerns.

11.4 SUMMARY OF DATA NEEDS

This section summarizes the data needs which have been identified in the discussions of research questions in Chapters 4.0 through 10.0. Largely for the convenience of the researcher who is applying the data needs, they are here compiled together into a single section.

11.4.1 Chronometrics Domain

Data needs to address these questions include:

- ▶ **samples for AMS radiocarbon dating** (charcoal, organic stains, pedogenic carbonates, soil/sediment, shell, bone);
- ▶ **samples for luminescence dating** from eolian, playa, and alluvial fan deposits;
- ▶ **lithic, ceramic, bone artifacts** for electron-spin resonance dating;
- ▶ **samples for cosmogenic isotope dating** of surfaces and surficial deposits;
- ▶ **lithics** for fission track dating;
- ▶ **fired features** for archeomagnetic dating;
- ▶ **wood samples** for dendrochronology;

- ▶ **lithics** for obsidian hydration and chert patination dating;
- ▶ **landsnails** for racemization dating;
- ▶ **rock varnish** samples for cation-ratio dating; and
- ▶ **temporally diagnostic artifacts.**

11.4.2 Geoarcheology Domain

Data needs to address these questions include:

- ▶ **stratigraphic exposures** of sites; and
- ▶ **sediment samples** for textural and chemical analysis from a variety of landforms.

11.4.3 Paleoenvironment Domain

Data needs to address these questions include:

- ▶ **sediment samples** of playas and lake bottoms/strands;
- ▶ **snail taxa** amenable to racemization analyses;
- ▶ **pedogenic carbonate samples** for radiocarbon dates and $\delta^{13}\text{C}$ values;
- ▶ **faunal and human remains** from archeological contexts;
- ▶ **tufa or travertine** deposits from spring, rockshelter, or cave sites;
- ▶ **wood** containing rings, from archeological or natural contexts;
- ▶ **phytoliths** from primary depositional contexts; and
- ▶ **wood and charcoal** fragments from archeological contexts.

11.4.4 Technology Domain

Data needs to address these questions include:

- ▶ **flaked lithic tools** for morphological, functional, and use-wear study;
- ▶ **groundstone tools** for morphological, functional, and use-wear study;
- ▶ **tools made from other materials** such as bone, horn, wood, fiber;

- ▶ **architectural features** such as rooms, walls, postholes;
- ▶ **non-structural features** such as trash pits, middens, storage facilities;
- ▶ **lithic raw material** sources and lithic procurement sites;
- ▶ **lithic caches**;
- ▶ **lithic debitage** assemblages;
- ▶ **lithic cores and biface** assemblages;
- ▶ **ceramics** for morphological, functional, and use-wear analysis; and
- ▶ **clay** and ceramic raw material sources.

11.4.5 Settlement Patterns Domain

Data needs to address these questions include:

- ▶ **site spatial patterns** from close interval pedestrian survey;
- ▶ **features**, especially hearths and structures;
- ▶ **lithics** for material source analysis;
- ▶ **lithic tools**;
- ▶ **ceramics and clay** material for sourcing; and
- ▶ **diverse artifact assemblages**.

11.4.6 Subsistence Domain

Data needs to address these questions include:

- ▶ **rock storage features**;
- ▶ **groundstone** artifacts;
- ▶ **macrobotanical** samples;
- ▶ **pollen and phytolith** samples;
- ▶ **ceramic vessels**;
- ▶ **animal bones**;
- ▶ **lithic tools and projectile points** for use-wear and source analyses;
- ▶ **preserved non-lithic tools** (nets, snares, clubs);
- ▶ **organic residues** on lithic tools;
- ▶ **human remains** for isotope analyses; and
- ▶ **human coprolites**.

11.4.7 Cultural Interaction Domain

Data needs to address these questions include:

- ▶ **local ceramics** for petrographic sourcing;
- ▶ **imported ceramics**;
- ▶ **local sources for clay and temper**;
- ▶ **ceramic rims**;
- ▶ **well dated lithic assemblages**;
- ▶ **lithic raw material procurement localities**;
- ▶ **site furniture** such as groundstone;
- ▶ **turquoise or calcite beads** for detailed sourcing;
- ▶ **copper bells or feathers** or other bird remains; and
- ▶ **artifact caches**.

11.5 A MODEL FOR ASSESSING SITE SIGNIFICANCE AT FORT BLISS

To assess research potential, and ultimately significance and NRHP eligibility, each prehistoric site at Fort Bliss must be matched against the identified data needs. In general, a site with more data sets has greater research potential than another site with fewer data sets. However, simplistic application of the equation *more = better* can introduce a bias against small sites, sparse sites, and/or common sites. Indeed, most archeologists are aware that careful investigation of a well preserved, single occupation site with sparse cultural remains can yield more important archeological knowledge than a similar investigation of a poorly preserved or vertically collapsed site with the proverbial "bucket-o-arrowheads."

Moreover, as has been discussed above, CRM archeology requires a focus on sites as units of management, without regard for other interesting or scientifically fruitful scales of focus. However, (contemporaneous) sites do not exist in isolation from one another; rather they co-exist in cultural *settlement systems* (indeed this is the entire focus of that research domain). Arguably, it is the settlement system, of which sites are merely components, which should be observed and evaluated. By way of illustration, current thought

in the population biology of threatened and endangered species suggests that awareness and protection of ecosystems is as important as is the physical protection of the species itself. Using this analogy, understanding cultural settlement systems is as important as understanding individual sites.

For example, consider a hypothetical subsistence/settlement system characterized by a seasonal pattern of dispersal during high resource availability periods and aggregation during low resource availability periods. In this situation, the archeological record might consist of a few long-term occupation sites with abundant material remains and a much higher number of short-term procurement sites with sparse material remains. Simplistic enumeration of various data sets identified in the research design (their frequency, diversity, or ubiquity) could easily favor the long-term sites as more "significant." If subsequent data recovery investigations focus only on the rich and diverse sites, then it is likely that an important aspect of the overall adaptive system would be missed entirely.

Because this problem is inherent in the CRM process itself, it can not be easily overcome. The site focus encourages treating each site equally, and while easy to implement, simple measures of site data content such as frequency, diversity, and/or ubiquity may not fully represent the research value of any given site.

Nonetheless, as illustrated in Figure 44, the process of evaluating prehistoric archeological sites at Fort Bliss for NRHP eligibility begins with two different classes of information: (1) resources already documented by previous surveys, and (2) resources not yet discovered. All resources must be evaluated according to the same criteria (data sets bearing on the research questions). However, as discussed above, the currently existing site database is a function of previous survey tactics, previous site definition policies, and earlier records management procedures. Therefore, several steps are necessary prior to reviewing empirical site data content in order to ensure comparability and integrity of the resulting database. First, all

documented cultural resources, including those which did not previously qualify as "sites," should be reviewed to determine whether they meet current site criteria. Secondly, the adequacy of existing documentation should be reviewed. If the site documentation is incomplete, missing, nonspecific, or poorly developed, then additional field work (remedial survey) is necessary to collect satisfactory survey level information.

Both new survey and remedial survey should be designed to make explicit observations about the nature, frequency, and ubiquity of the key data sets needed to address the natural context research domains and the cultural content research domains. The use of newly developed and standardized data forms (see Appendix A) are indicated to collect meaningful, replicable, and accurate information. For each site (whether newly recorded or archivally documented), a series of filters are then applied to evaluate overall research potential. These filters sequentially pose a series of minimum rejection criteria; at each filter, those sites not meeting the minimum criteria are rejected as having no research potential (see Figure 44).

First, the data sets bearing on the four cultural content research domains (Chapters 7.0 through 10.0) are reviewed and scored. These domains are technology, settlement patterns, subsistence, and cultural interaction. The scoring system used should be comparable to that devised for the natural context research domains (see Appendix A). The total score for each site is then compared to the minimum "rejection threshold" as specified in the CRMP. If the site does not meet the minimum threshold, it has no significant research potential and is not eligible for inclusion to the NRHP. If the recorded observations bearing on cultural content do not permit a clear rejection of the threshold criterion, then collection of additional data is warranted. Such data are generally collected by means of a subsequent "testing" phase. If however, the site significantly exceeds the threshold, it proceeds to the next filter.

The site is then assessed for chronometric potential, according to the data needs presented in

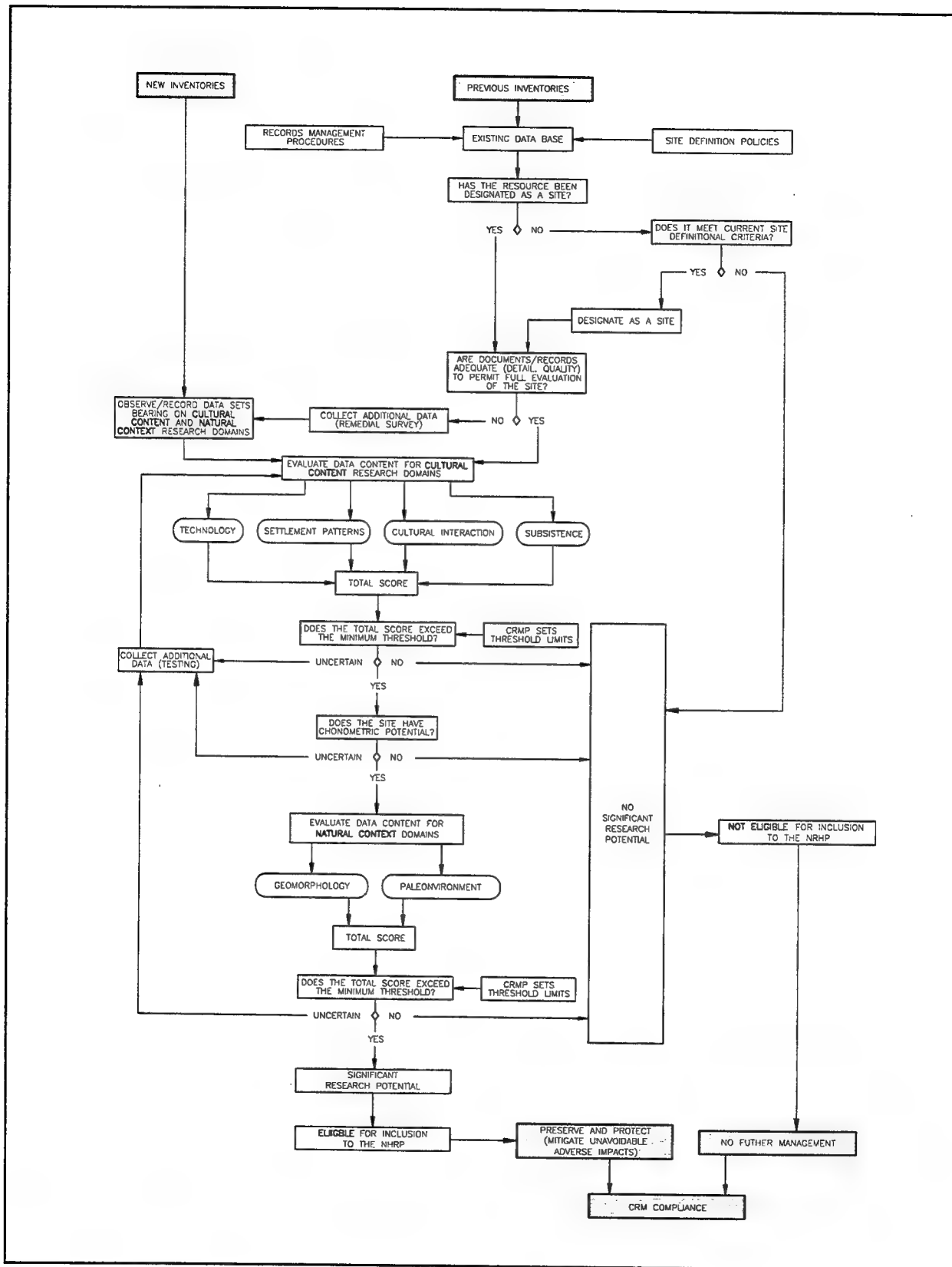


Figure 44 A Model of Site Significance Evaluation for Fort Bliss.

Chapter 4.0. If it does not contain any chronometric potential, it has no significant research potential and is not eligible for inclusion to the NRHP. If the recorded observations do not permit a clear determination, then collection of additional data is warranted. Again, such data are generally collected by "testing" the site. If however, the site has clear and promising chronometric potential, it proceeds to the final filter.

Finally, the site is assessed for context and integrity. The data sets bearing on the two natural context research domains, geomorphology and paleoenvironment (Chapters 5.0 and 6.0), are reviewed and scored using the system presented in Appendix A. The total score for each site is then compared to the minimum "rejection threshold" as specified in the CRMP. If the site does not meet the minimum threshold, it has no significant research potential and is not eligible for inclusion to the NRHP. Again, if the recorded observations bearing on natural context do not permit a clear rejection of the threshold criterion, then collection of additional data by means of testing is warranted. If however, the site significantly exceeds the rejection threshold, then it has passed all rejection filters and has significant research potential and is eligible for inclusion to the NRHP. By law, the site must be preserved and protected. If adverse impacts to the site can not be avoided, then these must somehow be mitigated.

12.0 REFERENCES CITED

- Abbott, J. T.
1995 Geomorphic/Stratigraphic evaluation of archaeological sites on the Salamayuca pipeline, El Paso Natural Gas Company, El Paso and Hudspeth Counties, Texas.
- Abel, P., S. M. Awramik, R. H. Osborne, and S. Tomellini
1982 Plio-Pleistocene Lacustrine Stromatolites from Lake Turkana, Kenya: Morphology, Stratigraphy, and Stable Isotopes. *Sedimentary Geology* 1:1-26.
- Abrahams, A. D., A. D. Howard, and A. J. Parsons
1994 Rock-mantled Slopes. In *Geomorphology of Desert Environments*, edited by Abrahams, A. D., and A. J. Parsons, pp. 173-212. Chapman and Hall, London.
- Adams, J. L.
1988 Use-Wear Analysis on Manos and Hide-Processing Stones. *Journal of Field Archaeology* 15:307-315.
1989 Methods for Improving the Analysis of Ground Stone Artifacts: Experiments in Mano Wear Pattern Analysis. In *Experiments in Lithic Technology*, D. S. Amick and R. P. Mauldin, editors, pp. 259-276. BAR International Series 528. Oxford.
1993 Technological Development of Manos and Metates on the Hopi Mesas. *Kiva*. 58:331-344.
- Aitken, M. J.
1985 *Thermoluminescence Dating*. London, Academic Press.
1989 Luminescence dating: A guide for non-specialists. *Archaeometry* 31(2):147-159.
1994 Optical dating: A non-specialist review. *Quaternary Geochronology* (Quaternary Science Reviews) 13:503-508.
- Akerston, W. A.
1970 Interpretation of sediments and vertebrate fossils in fill of Red Light Bolson, southeastern Hudspeth County, Texas. In *Geology of the southern Quitman Mountain area, Trans-Pecos, Texas: Society of Economic Paleontologists and Mineralogists, Permian Basin Section, Guidebook*, Pub. 70-11, pp. 82-87.
- Albritton, C. C., Jr., and Smith, J. F., Jr.
1965 Geology of the Sierra Blanca Area, Hudspeth County, Texas: *U.S. Geological Survey, Professional Paper* 479, 131 pp.
- Allan, J. R., and R. K. Matthews
1982 Isotopic Signatures Associated with Early Meteoric Diagenesis. *Sedimentology* 29:797-817.
- Almarez, F. A. and J. D. Leach
n.d. *The Hueco Mountain Cave and Rock Shelter Survey: A Phase I Baseline Inventory in Maneuver Area 2D on Fort Bliss, Texas*. Directorate of the Environment, Cultural and Natural Resources Division, Fort Bliss, Texas. Manuscript in preparation.
-

Alves, E. E.

1930 Shelter Caves of the El Paso District. *Bulletin of the Texas Archaeological and Paleontological Society* 2:64-68.

1932a A Small Ruin in New Mexico. *Bulletin of the Texas Archaeological and Paleontological Society* 4:40-43.

1932b Perishable Artifacts of the Hueco Caves. *West Texas Historical and Scientific Society Bulletin* 44:20-23. Sul Ross State Teacher's College, Alpine, Texas.

1934 Fetish Stones from near El Paso. *Bulletin of the Texas Archaeological and Paleontological Society* 7:70-74.

Ambrose, S. H.

1987 Chemical and Isotopic Techniques of Diet Reconstruction in Eastern North America. In *Emergent Horticultural Economies of the Eastern Woodlands*, W. F. Keegan, editor. Center for Archaeological Investigations, Occasional paper number 7. SIU, Carbondale.

Amick, D. S.

1991 *Folsom Landuse Patterns in the Southern Tularosa Basin*. Manuscript on file, Environmental Management Office, Fort Bliss, Texas.

1994 *Folsom Diet Breadth and Land Use in the American Southwest*. Unpublished Ph.D. dissertation, Department of Anthropology, University of New Mexico, Albuquerque.

1995 Patterns of Technological Variation Among Folsom and Midland Projectile Points in the American Southwest. *Plains Anthropologist* 40(151):23-38.

Amundson, R. G., O. A. Chadwick, J. M. Sowers, and H. E. Donner

1988 Relationship Between Climate and Vegetation and the Stable Carbon Isotope Chemistry of Soils in the Eastern Mojave Desert, Nevada. *Quaternary Research* 29:245-254.

Anderson, R. S.

1987 Eolian sediment transport as a stochastic process: The effects of a fluctuating wind on particle trajectories. *Journal of Geology* 95:497-512.

Anderson, S.

1993 Archaic Period Land Use in the Southern Tularosa Basin, New Mexico. In *Preliminary Investigations of the Archaic in the Region of Las Cruces, New Mexico*, edited by R. S. MacNeish. Historic and Natural Resources Report No. 9, Cultural Resources Management Program, Directorate of Environment, United States Army Air Defense Artillery Center, Fort Bliss, Texas.

Anschuetz, K. F.

1990 Archaeological Background. In *Landscape Archaeology in the Southern Tularosa Basin. Volume 1: Small Site Distributions and Geomorphology*, edited by K. F. Anschuetz, W. H. Doleman, and R. C. Chapman, pp. 17-37. Office of Contract Archaeology, University of New Mexico, Albuquerque.

Antevs, E.

1948 Climatic Changes and Pre-White Man in the Great Basin, with Emphasis on Glacial and Postglacial Times. *University of Utah Bulletin* 38:168-191.

1955 Geologic-climatic dating in the west. *American Antiquity* 20:317-335.

-
- Appenzeller, T.
1992 A high five from the first New World settlers? Bones, stones, and a palm print from a New Mexico cave could shake up New World archeologists. *Science* 255:920-921.
- Ascher, R.
1961 Analogy in archaeological interpretation. *Southwestern Journal of Anthropology* 17:317-325.
- Aten, L. E.
1972 Evaluation of the Cultural Resources of the Northgate Site, El Paso County, Texas. *Texas Archaeological Salvage Project, Research Report Number 5*. University of Texas at Austin, Texas.
- Azizov, A.
1977 Influence of soil moisture on the resistance of soil to wind erosion. *Soviet Soil Science* 9:105-108.
- Bachman, G. O., and M. N. Machette
1977 Calcic soils and calcretes in the Southwestern United States. *U. S. Geological Survey Open-File Report* 77-794.
- Bagnold, R. A.
1941 *The Physics of Blown Sand and Desert Dunes*. London, Chapman and Hall.
- Baldrige, W. S., K. H. Olsen, and J. F. Callender
1984 Rio Grande Rift: Problems and Perspectives. In *Rio Grande Rift: Northern New Mexico*, edited by W. S. Baldrige, P. W. Dickerson, R. E. Reicker, and J. Zidek. Guidebook, 35th Field Conference, New Mexico Geological Society, pp. 1-12.
- Bandelier, A. F.
1890 Investigations Among the Indians of the Southwest United States, Carried on Mainly in the Years From 1880-1885. *Papers of the Archaeological Institute of America American Series III, Part I*. University Press, Cambridge.
- Barkley, F. A.
1934 The statistical theory of pollen analysis. *Ecology* 15:283-289.
- Barnes, V. E.
1983 *Geologic Atlas of Texas: Van Horn-El Paso Sheet*. Bureau of Economic Geology, University of Texas at Austin.
- Bartlett, K.
1933 Pueblo milling stones of the Flagstaff region and their relation to others in the Southwest. *Museum of Northern Arizona Bulletin* No. 3. Northern Arizona Society of Science and Art, Flagstaff.
- Barsch, D., and C. F. J. Royse
1972 A model for development of Quaternary terraces and pediment-terraces in the southwestern United States of America. *Zeitschrift für Geomorphologie* 16:54.
- Basehart, H.
1973 *Mescalero Apache Subsistence Patterns in Technical Manual 1973 Survey of the Tularosa Basin*. Human Systems Research.
-

-
- 1974 Mescalero Apache Subsistence Patterns and Sociopolitical Organization. *American Indian Ethnohistory, Indians of the Southwest, Apache Indians, Volume 12*. Garland, New York.
- Basso, K. H.
1983 *Western Apache, in Handbook of North American Indians, Volume 10: Southwest*. Smithsonian Institution, Washington D.C.
- Bates, R. L., and J. A. Jackson
1984 *Dictionary of Geological Terms, 3rd Edition*. Prepared by the American Geological Institute. Garden City. Anchor Press/Doubleday, New York.
- Becker-Heidmann, P., and H. W. Scharpenseel
1986 Thin layer ^{13}C and $\delta^{14}\text{C}$ monitoring of 'lessive' soil profiles. *Radiocarbon* 28(2A):383-390.
- Beckes, M.
1977a Descriptive Analysis of Projectile Points. In *A Cultural Resource Inventory and Assessment of McGregor Guided Missile Range, Otero County, New Mexico*, pp. 41-80. Texas Archaeological Survey, Research Report No. 65, Parts I and II. The University of Texas at Austin.

1977b *Prehistoric Cultural Stability and Change in the Southern Tularosa Basin*. Unpublished Ph.D. dissertation, University of Pittsburgh.
- Beckes, M. R., D. S. Dibble, and M. D. Freeman
1977 A Cultural Resource Inventory and Assessment of McGregor Guided Missile Range, Otero County, New Mexico. *Texas Archaeological Survey, Research Report No. 65, Parts I and II*. The University of Texas at Austin.
- Beckett, P. H.
1980 Dune movement. In *The Ake Site: Collection and Excavation of LA13423, Catron County, New Mexico*, edited by P. H. Beckett, pp. 121-134. New Mexico State University, Cultural Resources Management Division, Report No. 357.

1983 The Paleoindian Prehistory of the Tularosa Basin. In *The Prehistory of Rhodes Canyon, N. M.*, edited by Pete L. Eidenbach. Human Systems Research, Tularosa, New Mexico.
- Beckett, P. H., and R. S. MacNeish
1987 *The Archaic Tradition of South Central New Mexico and Chihuahua, Mexico*. COAS Books, Las Cruces, New Mexico.
- Beckett, P. H., and T. L. Corbett
1992 *The Manso Indians*. COAS Publishing and Research, Las Cruces, New Mexico.
- Bell, W. H., and E. F. Castetter
1937 The Utilization of Mesquite and Screwbean by the Aborigines in the American Southwest. *The University of New Mexico Bulletin, Ethnobiological Studies in the American Southwest, Volume V*. The University of New Mexico Press, Albuquerque, New Mexico.

1941 The Utilization of Yucca, Sotol, and Beargrass by the Aborigines in the American Southwest. *The University of New Mexico Bulletin, Ethnobiological Studies in the American Southwest, Volume VII*. The University of New Mexico Press, Albuquerque, New Mexico.
-

Bender, M. M.

1968 Mass Spectrometric Studies of Carbon 13 Variations in Corn and Other Grasses. *Radiocarbon* 10:468-472.

1971 Variations in the C13/C12 Ratios of Plants in Relation to the Pathway of Photosynthetic Carbon Dioxide Fixation. *Phytochemistry* 10:1239-1244.

Bender, M. M., I. Rouhani, H. M. Vines, and C. C. Black

1973 ¹³C/¹²C Ratio Changes in Crassulacean Acid Metabolism Plants. *Plant Physiology* 52:427-430.

Bentley, M.

1992 *Preliterate Native Americans in the Paso del Norte Region*. Unpublished M. A. thesis. The University of Texas at El Paso.

1992a El Paso Brownware: A Preliminary Study of Clay Source Variability in the Hueco Bolson and Southern Tularosa Basin. In *Project 92-02: An Inventory Survey of Selected Quadrants of McGregor Range for RS JTX and the Ranger Training Battalion*, edited by D. E. Peter and S. Mbutu, pp. 372-394. Geo-Marine, Plano, Texas.

1992b Children of the Sun: One Aspect of Late Prehistoric and Early Historic Native American Religion in the El Paso Region. In *The Artifact*, 30(2):35-41. El Paso Archaeological Society, El Paso, Texas.

1994 The Tobin Well Investigation of Clay Sources and Prehistoric Pottery Through INAA. In *The Tobin Wells Archaeological Project*, edited by C. Lowry, Culture Resources Program, Directorate of the Environment, Fort Bliss, Texas.

Betancourt, J. L., P. S. Martin, and T. R. Van Devender

1983 Fossil packrat middens from Chaco Canyon, New Mexico: Cultural and ecological significance. In *Chaco Canyon Country: A Field Guide to the Geomorphology, Quaternary Geology, Paleoecology, and Environmental Geology of Northwestern New Mexico*, edited by S. G. Wells, D. W. Love, and T. W. Gardner, pp. 219-226. American Geomorphological Field Group 1983 Field Trip Guidebook.

Betancourt, J. L., T. R. Van Devender, and P. S. Martin

1990 *Packrat Middens the last 40,000 Years of Biotic Change*. The University of Arizona Press, Tucson.

Bettinger, R. L.

1977 Aboriginal Human Ecology in Owens Valley: Prehistoric Change in the Great Basin. *American Antiquity* 42:1:3-17.

Bettinger, R. L.

1980 Explanatory/Predictive Models of Hunter-Gatherer Adaptation. In *Advances in Archaeological Method and Theory* 3:189-255. Edited by Michael B. Schiffer. Academic Press, New York.

Bierman, P. R., and A. R. Gillespie

1994 Evidence suggesting that methods of rock varnish dating are neither comparable nor consistently reliable. *Quaternary Research* 41:82-90.

Binford, L. R.

1964 A Consideration of Archaeological Research Design. *American Antiquity* 29:425-441.

1965 Archaeological Systematics and the Study of Culture Process *American Antiquity*, 31:203-210.

-
- 1968 Methodological Considerations of the Archeological Use of Ethnographic Data. In *Man the Hunter*, edited by Richard B. Lee and Irven DeVore. Aldine, Chicago, Illinois.
- 1978 *Nunmuit Ethnoarcheology*. Academic Press, New York.
- 1979 Organization and Formation Processes: Looking at Curated Technologies. *Journal of Anthropological Research* 35:3:255-273.
- 1980 Willow Smoke and Dogs' Tails: Hunter-Gatherer Settlement Systems and Archaeological Site Formation. *American Antiquity* 45:1:4-20.
- 1981 Behavioral Archaeology and the Pompeii Premise. *Journal of Anthropological Research* 37(3):195-208.
- 1981 *Bones, Ancient Men and Modern Myths*. Academic Press, New York.
- 1982 The Archaeology of Place. *Journal of Anthropological Archaeology* 1:5-31.
- Binford, L. R. and J. Bertram
- 1977 Bone Frequencies and Attritional Processes. In *For Theory Building in Archaeology*, edited by L. R. Binford, pp. 77-153. Academic Press, New York.
- Birkeland, P. W.
- 1974 *Pedology, Weathering, and Geomorphological Research*. Oxford University Press, New York.
- 1984 *Soils and Geomorphology*. Oxford University Press, New York.
- 1985 Quaternary soils of the western United States. In *Soils and Quaternary Landscape Evolution*, pp. 303-324, edited by J. Boardman. John Wiley and Sons, New York.
- 1990 Soil-geomorphic research--A selective overview. *Geomorphology* 3:207-224.
- Bjorkman, O.
- 1976 Adaptive and Genetic Aspects of C4 Photosynthesis. In *CO₂ Metabolism and Plant Productivity*, B. Burris and C. C. Black, editors. University Park Press, Baltimore, Maryland.
- Black, C. C.
- 1973 Photosynthetic Carbon Fixation in Relation to Net CO₂ Uptake. *Annual Review of Plant Physiology* 24:253-286.
- Blackwelder, E.
- 1931 The lowering of the playa by deflation. *American Journal of Science* (5th Series) 21:140-144.
- Blair, T. C., and J. G. McPherson
- 1994 Alluvial fan processes and forms. In *Geomorphology of Desert Environments*, edited by A. D. Abrahms and A. J. Parsons, pp. 354-402. Chapman and Hall, New York.
- Blair, T. C., J. S. Clark, and S. G. Wells.
- 1990a Quaternary stratigraphy and landscape evolution and its application to archeological studies. In *Landscape Archaeology in the Southern Tularosa Basin, Volume 1: Small Site Distributions and Geomorphology*, edited by K. F. Anschultz, W. H. Doleman, and R. C. Chapman. University of New Mexico, Office of Contract Archaeology, pp. 167-212.
-

-
- 1990b Quaternary continental stratigraphy, landscape evolution, and application to archeology: Jarilla piedmont and Tularosa graben floor, White Sands Missile Range, New Mexico. *Geological Society of America Bulletin* 102:749-759.
- Blissenbach, E.
1954 Geology of alluvial fans in semiarid regions. *Geological Society of America Bulletin* 65:175-190.
- Blum, M. D., and S. Valastro, Jr.
1989 Response of the Pedernales River of Central Texas to Late Holocene Climatic Change. *Annals of the Association of American Geographers* 79:435-456.
- Blum, M. D., J. T. Abbott, and S. Valastro, Jr.
1992 Evolution of landscapes on the Double Mountain Fork of the Brazos River, West Texas: Implications for preservation and visibility of the archaeological record. *Geoarchaeology* 7(4):339-370.
- Bohrer, V. L.
1981 Former dietary patterns of people as determined from Archaic-age plant remains from Fresnal Shelter, South-Central New Mexico. *The Artifact* 19(3-4):41-50.
- Bousman, C. B.
1990 Paleoenvironments and human diets. In *Prehistoric Archeology and Paleoenvironments in Hildago and Willacy Counties, South Texas: Results of the Phase II Test Excavations*, by C. B. Bousman, S. A. Tomka, and G. L. Bailey, pp. 91-103. Austin, Texas, Prewitt and Associates, Report of Investigations 76.
- Boutton, T. W., A. T. Harrison, and B. N. Smith
1980 Distribution of biomass species differing in photosynthetic pathway along an altitudinal transect in southeastern Wyoming grassland. *Oecologia* 45:287-298.
- Boutton, T. W., P. D. Klein, M. J. Lynott, J. E. Price, and L. L. Tieszen
1984 Stable Carbon Isotope Ratios as Indicators of Prehistoric Diet. In *Stable Isotopes in Nutrition*. J. R. Turnlund and P. E. Johnson, editors. ACS Symposium Series 228, American Chemical Society, Washington D.C.
- Bozart, S.
1993 Maize (*Zea mays*) Cob Phytoliths From A Central Kansas Great Bend Aspect Archaeological Site. *Plains Anthropologist* 38:279-286.
- Bradbury, J. P.
1984 Potential of diatoms for dating and interpreting Quaternary lacustrine history in the western U. S. Abstract No. 33408. *Geological Society of America Abstracts with Programs*, 97th Annual Meeting, November 5-8 1984, Reno, Nevada.

1988 Fossil diatoms and Neogene paleolimnology. *Paleogeography, Paleoclimatology, and Paleoecology* 62:299-316.
- Bradfield, W.
1929 Excavations in the Sacramentos. In *El Palacio* XXVIII:3-6.
- Bradley, R. J.
1983 *La Cabrana: A Study of Fourteenth Century Resource Utilization in Southern New Mexico*. Unpublished M. A. thesis, The University of Texas at El Paso.
-

-
- 1992 Marine Shell Exchange in Northwest Mexico and the Southwest. In *The American Southwest and Mesoamerica: Systems of Prehistoric Exchange*, edited by J. E. Ericson and T. G. Baugh, pp. 121-151. Plenum Press, New York.
- Bradley, R. J. and J. M. Hoffer
- 1985 Playas Red: A Preliminary Study of Origins and Variability in the Jornada Mogollon. In *Proceedings of the Third Jornada Mogollon Conference*, edited by M. S. Foster and T. C. O'Laughlin, *The Artifact* 23, Numbers 1 and 2:161-177. El Paso Archaeological Society, El Paso.
- Bradley, R. S.
- 1985 *Quaternary Paleoclimatology*. Allen and Unwin, New York.
- Braun, D. P.
- 1983 Pots as Tools. In *Archaeological Hammers as Theories*, edited by A. Keene. Academic Press, New York.
- Breiner, S.
- 1973 Applications Manual for Portable Magnetometers. *Geometrics*. Sunnyvale, California.
- Breternitz, D. A.
- 1966 An Appraisal of Tree-ring Dated Pottery in the Southwest. *Anthropological Papers of the University of Arizona* 10. Tucson, Arizona.
- Brooks, V. L.
- 1979 An El Paso Astronomical Observatory. In *Jornada Mogollon Archaeology: Proceedings of the First Jornada Conference*, edited by P. H. Beckett and R. N. Wiseman, New Mexico State University, Las Cruces.
- Brook, V. R.
- 1966a They Didn't Barter to Fill the Larder. *The Artifact* 3:1-11.
- 1966b The McGregor Site. *The Artifact* 4:1-22.
- 1970 Four Archaeomagnetic Dates from the Hot Wells Site (EPAS-3). *The Artifact* 8(1).
- 1971 Some Hypotheses About Prehistoric Settlement in the Tularosa-Hueco Bolson Between A.D. 1250-1350. In *Transactions of the Sixth Regional Archaeological Symposium For Southeastern New Mexico and Western Texas*, pp. 63-82. El Paso Archaeological Society. El Paso, Texas.
- 1980 The Sabina Mountain Site. In *Transactions of the 15th Regional Archaeological Symposium for Southeastern New Mexico and Western Texas*, pp. 15-86. El Paso Archaeological Society. El Paso, Texas.
- Brookfield, M. E.
- 1977 The origin of bounding surfaces in ancient aeolian sandstones. *Sedimentology* 24:303-332.
- Brothwell, D. R.
- 1965 *Digging Up Bones*. The British Museum of Natural History, London.
- Browning, C., M. Sale, D. T. Kirkpatrick, and K. W. Laumbach
- 1992 *MOTR Site: Excavations at Site LA 72859, an El Paso Phase Structure on Ft. Bliss, Otero County, New Mexico*. Human Systems Research Report #8927, Las Cruces, New Mexico.
-

-
- Brugham, R. B.
1980 Postglacial diatom stratigraphy of Kirchner Marsh, Minnesota. *Quaternary Research* 13:133-146.
- Brush, N., M. Newman, and F. Smith
1994 Immunological Analysis of Flint Flakes from the Martins Creek Mastadon Site. *Current Research in the Pleistocene* 11:16-17.
- Bryant, V. M.
1974 Prehistoric diet in southwest Texas: The coprolite evidence. *American Antiquity* 39(3):407-420.
- Bryant, V. M., and R. Holloway
1983 The Role of Palynology in Archaeology. In *Advances in Archaeological Method and Theory* 6:121-224, edited by M. B. Schiffer. Academic press, New York.
- Bryson, R. A., D. A. Baerreis, and W. M. Wendlandt
1970 The character of Late-Glacial and Post-Glacial climatic changes. In *Pleistocene and Recent Environments of the Central Great Plains*, edited by W. Dort Jr. and J. K. Jones, pp. 53-74.
- Buck, B. J.
1993 Phytolith analysis of buried soils in the Fort Bliss Reservation, El Paso, Texas. In *Soil-Geomorphic and Paleoclimatic Characteristics of the Fort Bliss Maneuver Areas, Southern New Mexico and Western Texas*, edited by H. C. Monger, pp. 117-128. Historic and Natural Resources Report 10, pp. 117-131. Cultural Resources Management Program, Directorate of the Environment, United States Army Air Defense Artillery Center, Fort Bliss, Texas.
- Buckley, W. (editor)
1968 *Modern Systems Research for the Behavioral Scientist*. Aldine, Chicago, Illinois.
- Budd, L. F., R. B. Arend, J. W. Hurst, and V. H. Anderson
1979 *Fort Bliss Environmental Analysis and Assessment*. Report prepared for Environmental Office, Facilities Engineering, Fort Bliss, by Photographic Interpretation Corp, Hanover, New Hampshire.
- Büdel, J.
1983 *Climatic Geomorphology*. Princeton University Press. Princeton, New Jersey.
- Buffington, L. C., and Herbel, C. H.
1965 Vegetation changes on a semidesert grassland range. *Ecological Monographs* 35:139-164.
- Buikstra, J. E., and D. H. Ubelaker, (editors)
1994 Standards for Data Collection from Human Skeletal Remains. *Arkansas Archeological Survey Research Series* 44.
- Bull, W. B.
1968 Alluvial fan, cone. In *Encyclopedia of Geomorphology*, edited by R. W. Fairbridge, pp. 7-10. Reinhold, New York.

1977 The Alluvial Fan Environment. *Progress in Physical Geography* 1:222-270.

1991 *Geomorphic Responses to Climatic Change*. Oxford University Press, New York, New York.
-

Bumstead, P.

1984 *Human Variation: ¹³C in Adult Bone Collagen and the Relation to Diet in an Isochronous C4 (Maize) Archaeological Population*. Los Alamos National Laboratory, Los Alamos, New Mexico.

Burgett, G. R.

1994 Geomorphology of Eolian Environments and Archaeological Artifact Distributions: Questions of Integrity, Resolution, and Dimensional Scale. Draft of Paper Presented at the 52nd Plains Anthropological Conference, Lubbock, Texas. 47 pp. + Figures. Used with permission.

Buskirk, W.

1986 *The Western Apache Living with the Land Before 1950*. University of Oklahoma Press, Norman.

Butzer, K. W.

1982 *Archeology as Human Ecology: Method and Theory for a Contextual Approach*. Cambridge University Press, Cambridge.

Calamia, M. A.

1983 *Interpreting Human Mobility Through the Analysis of Ground Stone Implements*. Unpublished M. A. thesis, University of Illinois, Urbana-Champaign.

1991 Ground Stone Variability Among Jornada Mogollon Sites and Its Implications for Interpreting Residential Mobility. In *Mogollon V*, pp. 119-132. COAS Publishing and Research, Las Cruces, New Mexico.

Callender, I. F., J. W. Hawley, and G. R. Keller

1989 Rio Grande Rift. *28th International Geological Congress, Guidebook to Field Trip T318*, 37 pp.

Camilli, E. L.

1988 Interpreting Long-Term Land-Use Patterns from Archaeological Landscapes. *American Archaeology* 7:57-66.

Camilli, E. L., and J. I. Ebert

1992 Artifact Reuse and Recycling in Continuous Surface Distributions and Implications for Interpreting Land Use Patterns. In *Space, Time, and Archaeological Landscapes*, edited by J. Rossignol and L. Wandsnider pp. 113-136. Plenum Press, New York.

Camilli, E. L., L. Wandsnider, and J. I. Ebert

1988 Distributional Survey and Excavation of Archeological Landscapes in the Vicinity of El Paso, Texas. Report on file at the Las Cruces District, Office of the Bureau of Land Management.

Campbell, C. A., E. A. Paul, D. A. Rennie, and K. J. McCallum

1967 Factors affecting the accuracy of the carbon dating method in soil humus studies. *Soil Science* 104(2):81-85.

Cannon, K. P., and M. E. Newman

1994 Results of Blood Residue Analysis of a Late Paleoindian Projectile Point from Yellowstone National Park, Wyoming. *Current Research in the Pleistocene* 11:8-20.

Carlson, R. L.

1970 White Mountain Redware: A Pottery Tradition of East-Central Arizona and Western New Mexico. *Anthropological Papers No. 19*, University of Arizona Press, Tucson.

Carmichael, D. L.

1981 Non-Residential Occupation of the Prehistoric Southern Tularosa Basin, New Mexico. *The Artifact* 19(3,4):51-68.

1983 *Archeological Settlement Patterns in the Southern Tularosa Basin, New Mexico: Alternative Models of Prehistoric Adaptations*. Unpublished Ph.D. dissertation, University of Illinois, Urbana-Champaign.

1985a Archeological Excavations at Two Prehistoric Campsites Near Keystone Dam, El Paso, Texas. *University Museum Occasional Papers No. 14*. New Mexico State University, Las Cruces.

1985b Transitional pueblo occupation on Doña Ana Range, Fort Bliss, New Mexico. In *Views of the Jornada Mogollon*, edited by C. M. Beck, pp. 45-53. Eastern New Mexico University Contributions in Anthropology 12.

1986a Archaeological Survey in the Southern Tularosa Basin of New Mexico. Historic and Natural Resources Report No. 3. Environmental Management Office Directorate of Engineering and Housing, United States Army Air Defense Artillery Center, Fort Bliss, Texas. *Publications in Anthropology No. 10*. El Paso Centennial Museum, The University of Texas at El Paso.

1986b Ephemeral Residential Structures at Keystone Site 37: Implications for Interpreting Prehistoric Adaptive Strategies in the El Paso Area. *Mogollon Variability*, edited by C. Benson and S. Upham. *The University Museum Occasional Papers, No. 15*, New Mexico State University, Las Cruces.

1990 *Patterns of Residential Mobility and Sedentism in the Jornada Mogollon Area in Perspectives on Southwestern Prehistory*, edited by P. Minnis and C. Redman. Westview Press, Boulder, Colorado.

Carrigy, M. A.

1970 Experiments on the angle of repose of granular materials. *Sedimentology* 14:147-158.

Carson, M. A., and M. J. Kirkby

1972 *Hillslope Form and Process*. Cambridge University Press.

Castetter, E. F., and M. E. Opler

1936 The Ethnobiology of the Chiricahua and Mescalero Apache, Volume III:A. *The Use of Plants for Foods, Beverages, and Narcotics*. The University of New Mexico Bulletin, Ethnobiological Studies in the American Southwest, The University of New Mexico Press, Albuquerque.

Castetter, E. F., and W. H. Bell

1937 The Aboriginal Utilization of the Tall Cacti in the American Southwest, Volume IV. *The University of New Mexico Bulletin, Ethnobiological Studies in the American Southwest*. The University of New Mexico Press, Albuquerque.

Castetter, E. F., and R. M. Underhill

1935 The Ethnobiology of the Papago Indians. *The University of New Mexico Bulletin, Ethnobiological Studies in the American Southwest, Volume II*. The University of New Mexico Press, Albuquerque.

Castetter, E. F., W. H. Bell, and A. R. Grove

1938 The Early Utilization and the Distribution of Agave in the American Southwest. *The University of New Mexico Bulletin, Ethnobiological Studies in the American Southwest, Volume VI*. The University of New Mexico Press, Albuquerque.

Cattaneo, C. K., P. P. Gelsthorpe, and R. J. Sokol

1993 Blood residues on stone tools: indoor and outdoor experiments. *World Archaeology* 25:29-43.

Cerling, T. E.

1984 The stable isotopic composition of modern soil carbonate and its relationship to climate. *Earth and Planetary Science Letters* 71:229-240.

1990 Dating geomorphic surfaces using cosmogenic ^3He . *Quaternary Research* 33:148-156.

Champion, S.

1980 *Dictionary of Terms and Techniques in Archeology*. Facts on File, New York.

Chang, K. C.

1958 Study of the Neolithic Social Grouping: Examples from the New World. *American Anthropologist* 60:298-334.

Chapin, C. E., and W. R. Seager

1975 Evolution of the Rio Grande rift in the Socorro and Las Cruces areas. In *Guidebook of the Las Cruces Country*, edited by W. R. Seager, R. E. Clemons, and J. F. Callender. New Mexico Geological Society, Guidebook 26th field conference, pp. 297-321.

Chapman, K. M.

1926 An Archaeological Site in the Jornada del Muerto. *El Palacio* 20(6):24-28.

Chen, Y., S. Brumby, and J. Gao

1994 Observations on the suitability of the signal at $g = 2.0040$ for ESR dating of secondary carbonates. *Quaternary Geochronology* (Quaternary Science Reviews) 13:675-678.

Chepil, W. S., and N. P. Woodruff

1963 The physics of wind erosion and its control. *Advances in Agronomy* 15:211-302.

Child, A. M., and A. M. Pollard

1992 A Review of the Applications of Immunochemistry to Archaeological Bone. *Journal of Archaeological Science* 19:39-47.

Chorley, R. J., and B. A. Kennedy

1971 *Physical Geography: A Systems Approach*. Prentice Hall, London.

Chorley, R. J., S. A. Schumm, and D. E. Sugden

1984 *Geomorphology*. Methuen, London.

Christenson, A. L.

1986 Projectile Point Size and Projectile Aerodynamics: An Exploratory Study. *Plains Anthropologist* 31:109-128.

1987a The Prehistoric Tool Kit. In *Prehistoric Stone Technology on Northern Black Mesa, Arizona*, edited by W. J. Parry and A. L. Christenson, pp. 43-93. Center for Archaeological Investigation, Occasional Papers No. 12. Southern Illinois University press, Carbondale.

1987b The Economics of Change in Anasazi Maize Processing: The Evidence from Grinding Tools. In *Interpreting Western Pueblo Prehistory*, A. L. Christenson, editor.

Church, T., C. Caraveo, and J. Sirianni

1994 Swimming in a Sea of Permian Cherts: Results of the Fort Bliss Lithic Source Survey. Paper presented at the 52nd Plains Anthropology Conference, November, 1994. Lubbock, Texas.

Church, T., C. Caraveo, R. J., and J. Sirianni

n.d Mountains and Basins: The Lithic Landscape of Jornada Mogollon. Cultural Resources Management Program, Directorate of Environment, United States Army Air Defense Artillery Center, Fort Bliss, Texas. Manuscript in preparation.

Churchill, S. E.

1993 Weapon Technology, Prey Size Selection, and Hunting Methods in Modern Hunter-Gatherers: Implications for Hunting in the Paleolithic and Mesolithic. In *Hunting and Animal Exploitation in the Later Paleolithic and Mesolithic of Eurasia* edited by G. L. Peterkin, H. M. Bricker, and P. Mellars. Anthropological Papers of the American Anthropological Association No. 4.

Clark, G.

1977 *World Prehistory in New Perspective*. An Illustrated Third Edition. Cambridge University Press, Cambridge, Massachusetts.

Clarke, D. L.

1968 *Analytical Archaeology*. Methuen, London.

Clarke, M. L.

1994 Infra-red stimulated luminescence ages from aeolian sand and alluvial fan deposits from the eastern Mojave Desert, California. *Quaternary Geochronology* (Quaternary Science Reviews) 13:533-538.

Cliett, T.

1969 Groundwater occurrence of the El Paso area and its related geology. In *Guidebook of the Border Region*, edited by D. A. Córdoba, S. A. Wengerd, and J. Shomaker. New Mexico Geological Society, 20th Field Conference, pp. 209-214.

COHMAP Members

1988 Climatic changes of the last 18,000 years: Observations and model simulations. *Science* 241:1043-1052.

Collins, E. W., and J. A. Raney

1991 Tertiary and Quaternary Structure and Paleotectonics of the Hueco Basin, Trans-Pecos Texas and Chihuahua, Mexico. *University of Texas Bureau of Economic Geology Geological Circular* 91-2.

Colman, S. M., K. L. Pierce, and P. W. Birkeland

1987 Suggested terminology for Quaternary dating methods. *Quaternary Research* 28:314-319.

Cooke, R. U.

1970 Stone pavements in deserts. *Annals of the Association of American Geographers* 60:560-577.

Cooke, R. U., and A. Warren

1973 *Geomorphology in Deserts*. Batsford, London.

Cordell, L. S.

1984 *Prehistory of the Southwest*. Academic Press. Orlando, Florida.

Cordell, L. S., and F. Plog

1979 Escaping the Confines of Normative Thought: A Reevaluation of Puebloan Prehistory. *American Antiquity* 44:405-429.

Cosgrove, C. B.

1947 Caves of the Upper Gila and Hueco Areas in New Mexico and Texas. *Papers of the Peabody Museum of American Archaeology and Ethnology*, XXIV(2). Harvard University, Cambridge, Massachusetts.

Cosgrove, H. S., and C. B. Cosgrove

1932 The Swartz Ruin. *Papers of the Peabody Museum of American Archaeology and Ethnology* 15. Harvard University, Cambridge, Massachusetts.

Creel, D., R. F. Scott IV, and M. B. Collins

1990 A faunal record from west central Texas and its bearing on late Holocene bison population changes in the southern Plains. *Plains Anthropologist* 35(127):55-69.

Creel, D., and C. McKusick

1994 Prehistoric Macaws and Parrots in the Mimbres Area, New Mexico. *American Antiquity* 59(3):510-524.

Crimmins, M. L.

1929 An Archaeological Survey of the El Paso District. *Bulletin of the Texas Archaeological and Paleontological Society* 1:36-42.

1931 Pictographs at Hueco Tanks. *Bulletin of the Texas Archaeological and Paleontological Society* 3:24-30.

Cully, A. C., and K. H. Clary

1983 Pollen Analysis at Keystone Dam. In *The Keystone Dam Site*, by T. O'Laughlin. Centennial Museum Publications in Anthropology No. 8, University of Texas at El Paso, El Paso.

Cully, J.

1973a Tentative list of mammals on the west slope of the Sacramento Mountains. In *Technical Manual--1973 Survey of the Tularosa Basin, the Research Design*, pp. 202-203. Human Systems Research.

1973b Partial checklist of Avian Species on the Western Slope of the Sacramento Mountains. In *Technical Manual--1973 Survey of the Tularosa Basin, the Research Design*. Human Systems Research.

1973c *Survey of the Tularosa Basin, the Research Design*, pp.204-210. Human Systems Research.

Cummings, L. S.

1989 Pollen and Macrofloral Analyses. In *Archeological Excavations at the Gobernadora and Ojasen Sites: Dona Ana Phase Settlement in the Western Hueco Bolson, El Paso County, Texas*. By M. Miller, pp. 118-146. Center for Archaeological Research Report 673, New Mexico State University, Las Cruces.

1993 Phytolith Analysis of Three Locations on the Fort Bliss Military Reservation, New Mexico: A Feasibility Study. In *Soil-Geomorphic and Paleoclimatic Characteristics of the Fort Bliss Maneuver Areas, Southern New Mexico and West Texas*. Historic and Natural Resources Report No. 10, pp. 129-131. Archaeology Branch, Directorate of Environment, U.S. Army Air Defense Artillery Center, Fort Bliss.

Dan, J., D. H. Yaalon, R. Moshe, and S. Nissim

1982 Evolution of reg soils in southern Israel and Sinai. *Geoderma* 28:173-202.

-
- Daniel, A., J. Holechek, R. Valdez, A. Tembo, L. Saiwana, M. Fusco, and M. Cardenas
1993 Jackrabbit densities on fair and good condition Chihuahuan desert range. *Journal of Range Management* 46:524-528.
- Daniels, F., C. A. Boyd, and D. F. Sounders
1953 Thermoluminescence as a research tool. *Science* 117:343-349.
- Daniels, R. B., and R. D. Hammer
1992 *Soil Geomorphology*. John Wiley and Sons, New York.
- Dansgaard, W., and H. Tauber
1969 Glacier oxygen-18 content and Pleistocene ocean temperatures. *Science* 166:499-502.
- Davis, C. A., J. A. Medlin, and J. P. Griffing
1975 Abundance of Black-Tailed Jackrabbits, Desert Cottontail Rabbits, and Coyotes in Southeastern New Mexico. *New Mexico State Agricultural Experimental Station Research Report No. 293*:1-8. Las Cruces.
- Davis, O. K.
1989 The regionalization of climatic change in western North America. In *Paleoclimatology and Paleometeorology: Modern and Past Patterns of Global Atmospheric Transport*, edited by M. Leinen and M. Sarnthein, pp. 617-636. Amsterdam: Kluwer Academic.
- Davis, R., and O. A. Schaffer
1956 Chlorine-36 in nature. *Annals of the New York Academy of Sciences* 62:107-121.
- Dawson, P.
1993 Faunal Remains from Todson Cave. In *Preliminary Investigations of the Archaic in the Region of Las Cruces New Mexico*, edited by R. S. MacNeish, pp. 68-104. Historic and Natural Resources Report No. 9, Archaeology Branch, Directorate of Environment, U.S. Army Air Defense Artillery Center, Fort Bliss.
- Dean, G.
1989 Pollen Analysis of Samples From Seven Archaeological Sites, Loop 375 Archaeological Project, El Paso County, Texas. In *Loop 375 Archaeological Project, El Paso County, Texas*. An Interim Report for Phase II Additional Testing and Recommendations for Phase III Data Recovery. T. C. O'Laughlin and D. L. Martin. Manuscript prepared for the State Department of Highways and Public Transportation, Austin, Texas.

1994 Analysis of Flotation Samples from 16 Archaeological Sites, the Small Sites Project, Fort Bliss Military Reservation, Texas. Archaeobotanical Services Technical Series Report 921. In *Small Sites in the Central Hueco Bolson; A Final Report on Project 90-11*, by R. Mauldin, T. Graves, and M. Bentley. Historic and Natural Resources Report Series, Archaeology Branch, Directorate of Environment, U.S. Army Air Defense Artillery Center, Fort Bliss.
- Dean, J. S., and W. J. Robinson
1978 *Expanded Tree Ring Chronologies for the Southwestern United States*. Laboratory of Tree Ring Research, University of Arizona, Tucson.
- DeBoer, W. R.
1988 Subterranean Storage and the Organization of Surplus: The View From Eastern North America. *Southeastern Archaeology* 7(1):1-20.
-

Delorme, L. D.

1989 Methods in Quaternary Ecology #7: Freshwater Ostracodes. *Geoscience Canada* 16(2):85-90.

DeNiro, M. J.

1987 Stable Isotopy and Archaeology. *American Scientist* 75:183-191.

DeNiro, M. J., and S. Epstein

1978 Influences of Diet on the Distribution of Carbon Isotopes in Animals. *Geochemica et Cosmochemica Acta* 42:495-506.

Denison, R. E., and E. A. Hetherington

1969 Basement rocks in far west Texas and south-central New Mexico. In *Border Stratigraphy Symposium*, edited by F. E. Kottowski and D. V. LeMone. New Mexico Bureau of Mines and Mineral Resources, Circular 104, pp. 1-16.

Department of the Army

1984 *Fort Bliss Ongoing Mission Environmental Impact Statement, June 1984*. U. S. Army Air Defense Artillery Center and Fort Bliss.

Derr, P. S.

1981 *Soil Survey of Otero Area, New Mexico: Parts of Otero, Eddy, and Chaves Counties*. Washington: U. S. Department of Agriculture, Soil Conservation Service.

Devereaux, C. M.

1982 Climate speeds erosion of the Algarve's valleys. *The Geographical Magazine* 54:10-17.

Dillehay, T. D.

1972 Late Quaternary bison population changes on the southern Plains. *Plains Anthropologist* 19:177.

1974 Late Quaternary bison population changes on the southern Plains. *Plains Anthropologist* 19:185.

Dixon, J. C.

1994 Aridic soils, patterned ground, and desert pavements. In *Geomorphology of Desert Environments*, edited by Abrahms, A. D., and A. J. Parsons, pp. 64-81. Chapman and Hall, London.

Dohrenwend, J. C.

1994 Pediments in arid environments. In *Geomorphology of Desert Environments*, edited by Abrahms, A. D., and A. J. Parsons, pp. 321-353. Chapman and Hall, London.

Doleman, W. H., and T. C. Blair

1991 Field Guide to the Soils and Stratigraphy of the GBFEL-TIE Project Area. In *Landscape Archeology in the Southern Tularosa Basin, Volume 2: Testing, Excavation, and Analysis*, edited by W. H. Doleman, R. C. Chapman, J. A. Schutt, M. K. Swift, and K. D. Morrison, pp. 471-475. Report No. 185-324E, Office of Contract Archeology, University of New Mexico.

Doleman, W. H., and M. K. Swift

1991 Chapter 2: Geomorphological and environmental context of cultural remains. In *Landscape Archeology in the Southern Tularosa Basin, Volume 2: Testing, Excavation, and Analysis*, edited by W. H. Doleman, R. C. Chapman, J. A. Schutt, M. K. Swift, and K. D. Morrison, pp. 17-47. Report No. 185-324E, Office of Contract Archeology, University of New Mexico.

Doleman, W. H., R. C. Chapman, J. A. Schutt, M. K. Swift, and K. D. Morrison

1991 *Landscape Archeology in the Southern Tularosa Basin, Volume 2: Testing, Excavation, and Analysis*. Prepared for U.S. Army Engineer District, Fort Worth Contract No. DACA63-91-C-100. OCA/UNM Report No. 185-324E, WSMR Archeological Report No. 91-9. Office of Contract Archeology, University of New Mexico.

Dorn, R. I.

1988 A rock varnish interpretation of alluvial fan development in Death Valley, California. *National Geographic Research* 4:56-73.

1994 The role of climate change in alluvial fan development. In *Geomorphology of Desert Environments*, edited by A. D. Abrahms, and A. J. Parsons, pp.593-615. Chapman and Hall, London.

Dorn, R. I., and T. M. Oberlander

1982 Rock varnish. *Progress in Physical Geography* 6:317-367.

Dorn, R. I., D. B. Bamforth, T. A. Cahill, J. C. Dohrwend, B. D. Turrin, D. J. Donahue, A. J. T. Jull, A. Long, M. E. Macko, E. B. Weil, D. S. Whitley, and T. H. Zabel

1986 Catio-ratio and accelerator radiocarbon dating of rock varnish on Mojave artifacts and landform surfaces. *Science* 231:830-833.

Dorn, R. I., B. D. Turrin, A. J. Jull, T. W. Linick, and D. J. Donohue

1987 Radiocarbon and cation-ratio ages for rock varnish on Tioga and Tahoe morainal boulders of Pine Creek, eastern Sierra Nevada, California, and their paleoclimatic implications. *Quaternary Research* 28:38-49.

Dorn, R. I., A. J. T. Jull, D. J. Donohue, T. W. Linick, and L. J. Toolin

1989 Accelerator mass spectrometry radiocarbon dating of rock varnish. *Geological Society of America Bulletin* 101:1363-1372.

Douglass, A. E.

1919 Climatic cycles and tree growth, Volume 1. *Carnegie Institution of Washington Publication No. 289*. Carnegie Institution, Washington D.C.

Downs, E. F.

1993 Organic Residues on Ancient Lithic Artifacts from the Las Cruces Area of New Mexico. In *Preliminary Investigations of the Archaic in the Region of Las Cruces New Mexico*, edited by R. S. MacNeish, pp. 123-129. Historic and Natural Resources Report No. 9, Archaeology Branch, Directorate of Environment, U.S. Army Air Defense Artillery Center, Fort Bliss.

Dreimanis, A., G. Hütt, A. Raukas, and P. W. Whipp

1985 Dating Methods of the Pleistocene and their Problems: I. Thermoluminescence Dating. In *Dating Methods of the Pleistocene and their Problems*, reprinted with revisions from a series of papers in Geoscience Canada 1978-1982, edited by N. W. Rutter, pp. 1-7. Geoscience Canada, Reprint Series 2.

Drew, L. G., (editor)

1972 Tree-Ring Chronologies of Western North America. *Chronological Series 1, Laboratory of Tree Ring Research*. University of Arizona.

Dulaney, A. R., and J. D. Pigott

1977 Preliminary Technological Analysis of El Paso Brownware and Design for Further Research. In *A Cultural Resource Inventory and Assessment of McGregor Guided Missile Range, Otero County, New Mexico, Part II:*

Special Archeological Studies, pp. 265-289. Research Report No. 65, Part II, Texas Archeological Survey, The University of Texas at Austin.

Dumas, D. B.

1980 Seismicity in the Basin and Range province of Texas and northeast Chihuahua, Mexico. In *Trans-Pecos Region, southeastern New Mexico and West Texas*, edited by P. W. Dickerson, J. M. Hoffer, and J. F. Callender, pp. 77-81. New Mexico Geological Society Annual Field Conference Guidebook 31.

Duncan, R. B., and W. H. Doleman

1991 Fire-Cracked Rock Studies. In *Landscape Archaeology in the Southern Tularosa Basin, Volume 2: Testing, Excavation, and Analysis*, edited by W. H. Doleman, R. C. Chapman, J. A. Schutt, M. K. Swift, and K. D. Morrison. OCA/UNM Report No. 185-324E. WSMR Archaeological Report No. 91-9. Office of Contract Archaeology, University of New Mexico, Albuquerque.

Dunn, F. L.

1968 Epidemiological Factors: Health and Disease in Hunter-Gatherers. In *Hunters and Gatherers Today a Socioeconomic Study of Eleven Such Cultures in the Twentieth Century*, edited by M. G. Bicchieri, pp. 221-228. Holt, Rinehart and Winston, New York.

Earle, T. K., and J. E. Ericson

1977 Exchange Systems in Archaeological Perspective. In *Exchange Systems in Prehistory* edited by Timothy K. Earle and Jonathan E. Ericson, pp. 3-12. Academic Press, New York.

Edwards, S. R.

1993 Luminescence dating of sand from the Kelso Dunes, California. In *The Dynamics and Environmental Context of Aeolian Sedimentary Systems*, edited by K. Pye, pp. 59-68. Geological Society of America Special Publication No. 72.

Eicher, T. F.

1978 *Some Life History Characteristics and Habitat Use of Mule Deer in the Sacramento Mountains*. Unpublished M.S. thesis, New Mexico State University, Las Cruces.

Eighmy, J. L.

1980 Archeomagnetism: A Handbook for the Archeologist. *U.S. Department of the Interior, Heritage Conservation and Recreation Service Publication 58*, Washington, D.C.

Eisele, J.

1994 Survival and Detection of Blood Residue Analysis on Stone Tools. University of Nevada, Reno. *Department of Anthropology Technical Report 94-1*, Reno.

Elias, S. A., and T. R. Van Devender

1990 Fossil insect evidence for Late Quaternary climatic change in the Big Bend region, Chihuahuan Desert, Texas. *Quaternary Research* 34:249-261.

1992 Insect fossil evidence of Late Quaternary environments in the northern Chihuahuan Desert of Texas and New Mexico: Comparisons with the paleobotanical record. *The Southwestern Naturalist* 37(2):101-116.

Ellis, G. L., C. Lintz, W. N. Trierweiler, and J. M. Jackson

1994 Significance Standards for Prehistoric Cultural Resources: A Case Study from Fort Hood, Texas. *USACERL Technical Report CRC-94/04*. United States Army Corps of Engineers, Construction Engineering Research Laboratories. Urbana, Illinois.

Ellis, G. L., and G. A. Goodfriend

1994 Chronometric and Site Formation Studies Using Land Snails. In *Archeological Investigations on 571 Prehistoric Sites at Fort Hood, Bell and Coryell Counties, Texas*, edited by W. N. Trierweiler, pp. 183-201. Archeological Resource Management Series Research Report No. 31. Fort Hood, Texas.

Emeliani, C.

1955 Pleistocene Temperatures. *Journal of Geology* 63:538-578.

Epstein, S., R. P. Sharp, and A. J. Gow

1970 Antarctic Ice Sheet: Stable Isotope Analyses of the Byrd Station Cores and Interhemispheric Climatic Implications. *Science* 168:1570-1572.

Ericson, J. E., and T. G. Baugh

1993 Trade and Exchange in a Historical Perspective. In *The American Southwest and Mesoamerica Systems of Prehistoric Exchange*, pp. 3-20. Plenum Press, New York.

Evans, L. J.

1985 Dating Methods of Pleistocene Deposits and their Problems: VII. Paleosols. In *Dating Methods of Pleistocene Deposits and their Problems*, edited by N. W. Rutter. Geoscience Canada, Reprint Series 2, pp. 53-59.

Farnsworth, P., J. E. Brady, M. J. DeNiro, and R. S. MacNeish

1985 A Re-evaluation of the Isotopic and Archaeological Reconstructions of Diet in the Tehuacan Valley. *American Antiquity* 50:102-116.

Felgenhauer, F., J. Fink, and H. de Vries

1959 Studien zur absoluten und relativen Chronologie der fossilen Boden in Österreich. *Archaeologia Austriaca* 25:35-73.

Fenneman, N. M.

1931 *Physiography of the Western United States*. McGraw Hill, New York.

Ferring, C. R.

1986 Late Quaternary geology and environments of the upper Trinity Basin. In *An Assessment of the Cultural Resources in the Trinity River Basin, Dallas, Tarrant, and Denton Counties, Texas*, edited by B. C. Yates and C. R. Ferring, pp.32-112. University of North Texas, Denton.

Fewkes, J. W.

1902 The Pueblo Settlements near El Paso, Texas. *American Anthropologist* 4:57-75.

Fields, R. C., and J. S. Girard

1983 Investigations at Site 32 (41 EP 325), Keystone Dam Projects. *Reports of Investigations, Number 21*. Prewitt and Associates, Austin, Texas.

Flannery, K. V.

1968 Archaeological systems theory and early Mesoamerica. In *Anthropological Archaeology in the Americas*, edited by B. J. Meggers, pp. 67-87. Anthropological Society of Washington, Washington D.C.

Folk, R. L.

1970 Longitudinal dunes of the northwestern edge of the Simpson Desert, Northern Territory, Australia 1: Geomorphology and grain size relationships. *Sedimentology* 16:5-54.

Forbes, J. D.

- 1957 The Janos, Jocomes, Mansos, and Sumas Indians. In *New Mexico Historical Review*. 32:4:319-334. Historical Society of New Mexico and the University of New Mexico, Albuquerque.

Ford, R. I.

- 1977 Archaeobotany of Fort Bliss Maneuver Area II, Texas. Appendix E In *Settlement Patterns of the Eastern Hueco Bolson*, by M. Whalen. Anthropological Paper Number 4, Centennial Museum, University of Texas at El Paso.

Fort Bliss

- 1993 *Fort Bliss Sun Country*. Fort Bliss Installation Guide. MARCOA, San Diego, California.

Foster, M. S.

- 1993 *Archaeological Investigations at Pueblo Sin Casas (FB6273), A Multicomponent Site in the Hueco Bolson, Fort Bliss, Texas*. Historic and Natural Resources Report No. 7. Cultural Resources Management Program, Directorate of Environment, United States Army Air Defense Artillery Center, Fort Bliss, Texas.

Foster, M. S., and R. J. Bradley

- 1984 La Cabrana: A Preliminary Discussion of a Jornada Mogollon Pueblo. In *Recent Research in Mogollon Archeology*, edited by S. Upham, F. Plog, D. G. Batcho, and B. Kauffman. The University Museum, New Mexico State University, Occasional Papers, Number 10, Las Cruces, New Mexico.

Foster, M., R. J. Bradley, and C. Williams

- 1981 Prehistoric Diet and Subsistence Patterns of La Cabrana Pueblo. *The Artifact* 19(3,4):151-168.

Fowler, A. J., R. Gillespie, and R. E. M. Hedges

- 1986 Radiocarbon dating of sediments. *Radiocarbon* 28(2A):441-450.

Francis, C. F.

- 1994 Plants on desert hillslopes. In *Geomorphology of Desert Environments, Abrahms*, edited by A. D., and A. J. Parsons, pp. 243-254. Chapman and Hall, London.

Francis, J. E., L. L. Loendorf, and R. I. Dorn

- 1993 AMS radiocarbon and cation-ratio dating of rock art in the Bighorn Basin of Wyoming and Montana. *American Antiquity* 58:711-738.

Franseschetti, B.

- 1962 *La degradazione accelerata nei bacini montani del Fiume Astico e dei Torrenti La Varda e Longhella*. L'Erosione del Suolo in Italia I, Consiglio Nazionale delle Ricerche Cento di Studio per la Geografica Fisica, Padua.

Frederick, C. D.

- 1993 Geomorphology. In *Historic and Prehistoric Data Recovery at Palo Duro Reservoir, Hansford County, Texas*, by J. M. Quigg, C. Lintz, F. M. Oglesby, A. C. Earls, C. D. Frederick, W. N. Trierweiler, D. Owlsley, and K. W. Kibler. Mariah Associates Technical Report No. 485, Austin.

Frederick, C. D., M. D. Glasscock, H. Neff, and C. M. Stevenson

- 1994 *Evaluation of Chert Patination as a Dating Technique: A Case Study from Fort Hood, Texas*. United States Army Fort Hood, Archeological Resource Management Series, Research Report No. 32. Fort Hood, Texas.
-

Freeman, C. E.

1972 Pollen study of some Holocene alluvial deposits in Dona Ana County, southern New Mexico. *Texas Journal of Science* 24(2):203-220.

Frink, D. S.

1992 The chemical variability of carbonized organic matter through time. *Archaeology of Eastern North America* 20:67-79.

1994 The oxidizable carbon ratio (OCR): A proposed solution to some of the problems encountered with radiocarbon data. *North American Archaeologist* 15:17-29.

1995 Application of the oxidizable carbon ratio dating procedure and its implications for pedologic research. In *Pedological Perspectives in Archeological Research, Soil Science Society of America Special Publication 44*, pp. 95-106.

Fritts, H. C.

1962 An approach to dendroclimatology screening by means of multiple regression techniques. *Journal of Geophysical Research* 67:1413-1420.

1976 *Tree Rings and Climate*. Academic Press, New York.

Fryberger, S. G., T. S. Ahlbrandt, and S. Andrews

1979 Origin, sedimentary features, and significance of low-angle eolian sand sheet deposits, Great Sand Dunes National Monument and vicinity, Colorado. *Journal of Sedimentary Petrology* 49(3):733-746.

Fuller, I. C., A. G. Wintle, and G. A. T. Duller

1994 Test of the partial bleach methodology as applied to the infra-red stimulated luminescence of an alluvial sediment from the Danube. *Quaternary Geochronology* (Quaternary Science Reviews) 13:539-543.

Garrison, E. G., R. M. Rowlett, D. L. Cowan, and L. V. Holroyd

1981 ESR dating of ancient flints. *Nature* 290:44-45.

Geyh, M. A., J. H. Benzler, and G. Roeschmann

1971 Problems of dating Pleistocene and Holocene soils by radiometric methods. In *Paleopedology: Origin, Nature, and Dating of Paleosols*, D. Yaalon, editor. Israel University Press, New York.

Geyh, M. A., G. Roeschmann, T. A. Wijmstra, and A. A. Middeldorp

1983 The unreliability of ^{14}C dates obtained from buried sandy podsols. *Radiocarbon* 25:409-416.

Geyh, M. A., and H. Schleicher

1990 *Absolute Age Determination: Physical and Chemical Dating Methods and Their Application*. Translated by R. C. Newcomb. Springer Verlag, New York.

Gile, L. H.

1966a Coppice dunes and the Rotura soil. *Soil Science Society of America Proceedings* 30:657-660.

1966b Cambic and certain noncambic horizons in desert soils of southern New Mexico. *Soil Science Society of America Proceedings* 31(6):773-781.

1975a Causes of soil boundaries in an arid region; I. age and parent materials. *Soil Science Society of America Proceedings* 39:316-323.

-
- 1975b Causes of soil boundaries in an arid region; II. dissection, moisture, and faunal activity. *Soil Science Society of America Proceedings* 39:324-330.
- 1975c Holocene soils and soil-geomorphic relations in an arid region of southern New Mexico. *Quaternary Research* 5:321-360.
- 1987a Late Holocene displacement along the Organ Mountains fault in southern New Mexico. *New Mexico Bureau of Mines and Mineral Resources, Circular* 196, 43.
- 1987b A pedogenic chronology for Kilbourne Hole, Southern New Mexico II: Time of the explosion and soil events before the explosions. *Soil Science Society of America Journal* 51:752-760.
- Gile, L. H. and R. B. Grossman
1979 *The Desert Project soil monograph*. Document PB80-135304, National Technical Information Service, Springfield, Virginia.
- Gile, L. H., F. F. Peterson, and R. B. Grossman
1966 Morphological and genetic sequences of carbonate accumulation in desert soils. *Soil Science* 101:347-360.
- Gile, L. H., J. W. Hawley, and R. B. Grossman
1981 *Soils and geomorphology in the Basin and Range area of southern New Mexico--Guidebook to the Desert Project*. New Mexico Bureau of Mines and Mineral Resources, Memoir 39, Socorro.
- Gilet-Blein, N., G. Marien, and J. Evin
1980 The unreliability of ^{14}C dates from organic matter of soils. *Radiocarbon* 22:919-929.
- Gillespie, R., I. P. Prosser, E. Dlugokencky, R. J. Sparks, G. Wallace, and J. M. A. Chappell
1992 AMS dating of alluvial sediments on the southern tablelands of New South Wales, Australia. *Radiocarbon* 34(1):29-36.
- Gilman, P.
1983 *Changing Architectural Forms in the Prehistoric Southwest*. Unpublished Ph.D. dissertation, The University of New Mexico, Albuquerque.
- Gilman, P. A., V. Canouts, and R. L. Bishop
1994 The Production and Distribution of Classic Mimbres Black-on-White Pottery. *American Antiquity* 59(4):695-709.
- Gish, J. W.
1993 Pollen results from three study localities on the Fort Bliss Military Reservation, New Mexico. In *Soil-Geomorphic and Paleoclimatic Characteristics of the Fort Bliss Maneuver Areas, Southern New Mexico and Western Texas*, edited by H. C. Monger, pp. 93-115. Historic and Natural Resources Report 10, Cultural Resources Management Program, Directorate of the Environment, United States Army Air Defense Artillery Center, Fort Bliss, Texas.
- Gladwin, H. S.
1934 The Archaeology of the Southwest and its Relation to the Cultures of Texas. *Bulletin of the Texas Archaeology and Paleontological Society* 6:19-35.
- 1936 Methodology in the Southwest. *American Antiquity* 1:256-259.
-

Gladwin, W., and H. S. Gladwin

1934 *A Method for the Designation of Cultures and Their Variations, Medallion Papers, No. 15.* Globe, Arizona.

1934 *Methods for the Designation of Cultures. Medallion Papers No. 1.* Gila Pueblo, Globe, Arizona.

Glennie, K. W.

1970 *Desert Sedimentary Environments.* Elsevier Press, Amsterdam.

Glennie, K. W., and B. D. Evamy

1968 Dikaka: Plants and plant root structures associated with aeolian sand. *Paleogeography, Palaeoclimatology, and Palaeoecology* 4:77-87.

Glover, T. G.

1975 Geology of the central Organ Mountains, Doña Ana County, New Mexico. In *Guidebook of the Las Cruces Country*, edited by W. R. Seager, R. E. Clemons, and J. F. Callender, pp. 157-161. New Mexico Geological Society Guidebook, 26th Field Conference.

Goh, K. M.

1980 Dynamics and stability of organic matter. In *Soils with Variable Charge*, edited by B. K. G. Theng. New Zealand Society of Soil Science.

Goh, K. M., and B. P. J. Malloy,

1978 Radiocarbon dating of paleosols using soil organic matter components. *Journal of Soil Science* 29:567-573.

Göksu, H. I., J. H. Fremlin, H. T. Irwin, and R. Fryxell

1974 Age determination of burned flint by a thermoluminescence method. *Science* 183:651-654.

Goodfriend, G. A.

1987 Chronostratigraphic Studies of Sediments in the Negev Desert, Using Amino Acid Epimerization Analysis of Land Snail Shells. *Quaternary Research* 28:374-392.

Goodman, M. E.

1944 The Physical Properties of Stone Tool Materials. *American Antiquity* 4:415-433.

Gordon, D., P. L. Smart, D. C. Ford, J. N. Andrews, T. C. Atkinson, P. J. Rowe, and N. S. J. Christopher

1989 Dating of Late Pleistocene Interglacial and Interstadial Periods in the United Kingdom from Speleothem Growth Frequency. *Quaternary Research* 31:14-26.

Gorman, F.

1972 The Clovis Hunters: An Alternate View of Their Environment and Ecology. In *Contemporary Archaeology A Guide to Theory and Contributions*, edited by M. P. Leone. pp. 206-221. Southern Illinois University Press. Carbondale.

Gossett, C. W.

1985 Projectile Points as Chronological Indicators. In *Class II Cultural Resource Survey, Upper Gila Supply Study, Central Arizona Projects*, edited by R. Chapman, C. W. Gossett, and W. J. Gossett, pp. 104-130. Deuel and Associates, Albuquerque, New Mexico.

Goudie, A. S.

1983 Calcrete. In *Chemical Sediments and Geomorphology: Precipitates and Residua in the Near-surface Environment*, edited by A. S. Goudie and K. Pye, pp. 93-131. Academic Press, New York.

-
- Gould, R. A.
1980 *Living Archaeology*. New Studies in Archaeology. Cambridge University Press.
- Graham, R. W.
1987 Late Quaternary mammalian faunas and paleoenvironments of the southwestern Plains of the United States. In *Late Quaternary Mammalian Biogeography and Environments of the Great Plains and Prairies*, edited by R. G. Graham, H. A. Semken, and M. A. Graham, Illinois State Museum Scientific Papers 22, pp. 24-86.
- Gray, J., and P. Thompson
1976 Climatic Information from the 18O/16O Ratios of Cellulose in Tree Rings. *Nature* 262:481-482.
- Grayson, D. K.
1984 *Quantitative Zooarchaeology, Topics in the Analysis of Archeological Faunas*. Academic Press, New York.

1989 Bone Transport, Bone Destruction, and Reverse Utility Curves. *Journal of Archaeological Science* 16:643-652.
- Greeley, R., and J. D. Iversen
1985 *Wind as a Geological Process*. Cambridge University Press.
- Greer, J. W.
1968 Notes on Excavated Ring Midden Sites, 1963-1968. *Bulletin of the Texas Archaeological Society* 38:39-44.
- Grime, J. P.
1977 Evidence for the Existence of Three Primary Strategies in Plants and its Relevance to Ecological and Evolutionary Theory. *American Naturalist* 111:1169-1194.
- Grün, R., H. P. Schwarcz, D. C. Ford, and D. Hentzsch
1988 ESR dating of spring-deposited carbonates. *Quaternary Science Reviews* 7:429-432.
- Gurfinkel, D. M., and U. M. Franklin
1988 A study of the feasibility of detecting blood residue on artifacts. *Journal of Archaeological Science* 15:83-97.
- Gustavson, T. C.
1986 A possible origin of the Tule Basin. In *Geomorphology and Quaternary Stratigraphy of the Rolling Plains, Texas Panhandle*, edited by T. C. Gustavson. Guidebook 22, Bureau of Economic Geology, University of Texas at Austin, pp. 73-78.

1991 *Arid Basin Depositional Systems and Paleosols: Fort Hancock and Camp Rice Formations (Pliocene-Pleistocene), Hueco Bolson, West Texas and Adjacent Mexico*. University of Texas Bureau of Economic Geology Report of Investigations No. 198.
- Haas, H., V. Holliday, and R. Stuckenrath
1986 Dating of Holocene Stratigraphy with Soluble and Insoluble Organic Fractions at the Lubbock Lake Archaeological Site, Texas: An Ideal Case Study. *Radiocarbon* 28(2A):473-485.
- Hall, S. A.
1982 Late Holocene paleoecology of the Southern Plains. *Quaternary Research* 17:391-407.
-

-
- 1983 Holocene stratigraphy and paleoecology of Chaco Canyon. In *Chaco Canyon Country: A Field Guide to the Geomorphology, Quaternary Geology, Paleoecology, and Environmental Geology of Northwestern New Mexico*, edited by S. G. Wells, D. W. Love, and T. W. Gardner, pp. 219-226. American Geomorphological Field Group 1983 Field Trip Guidebook.
- 1985 Quaternary pollen analysis and vegetational history of the Southwest. In *Pollen Records of Late-Quaternary North American Sediments*, edited by V. M. Bryant and R. G. Holloway, pp. 95-123. American Association of Stratigraphic Palynologists, Dallas, Texas.
- 1990a Channel trenching and climate change in the southern U.S. Great Plains. *Geology* 18:342-345.
- 1990b Pollen evidence for historic vegetation change, Hueco Bolson, Texas. *Texas Journal of Science* 42(4):399-403.
- 1990c Holocene landscapes of the San Juan Basin, New Mexico: Geomorphic, climatic, and cultural dynamics. In *Archaeological Geology of North America*, edited by N. P. Lasca and J. Donahue, pp. 323-334.
- Hammond, G. P., and A. Rey
1966 *The Rediscovery of New Mexico 1580-1594*. University of New Mexico Press, Albuquerque.
- Hanks, P. (editor)
1986 *Collins Dictionary of the English Language*. Second Edition, William Collins Sons, London.
- Harbour, R. L.
1972 Geology of the Northern Franklin Mountains, Texas and New Mexico. *U.S. Geological Survey, Bulletin* 1298:129.
- Hard, R. J.
1982 Settlement and Subsistence in the Chihuahuan Desert: Cultural-Ecological Models for Fort Bliss, Texas. Proceedings of the American Society for Conservation Archaeology. Manuscript on file at Environmental Protection Office, Fort Bliss, Texas.
- 1983a A Model for Prehistoric Land Use, Fort Bliss, Texas. *Proceedings* 1983:41-51. American Society for Conservation Archaeology.
- 1983b Excavations in the Castner Range Archeological District in El Paso, Texas. *Publications in Anthropology No. 11*, El Paso Centennial Museum, The University of Texas at El Paso.
- 1986 *Ecological Relationships Affecting the Rise of Farming Economies: A Test From the American Southwest*. Unpublished Ph.D. dissertation, Department of Anthropology, University of New Mexico, Albuquerque.
- 1990 Agricultural Dependence in the Mountain Mogollon. In *Perspectives on Southwestern Prehistory*, edited by P. E. Minnis and C. L. Redman, pp. 135-149. Westview Press, Boulder, Colorado.
- n.d. Conejo Site Excavation Field Notes. Manuscript on file, Directorate of the Environment, Archaeology Branch, Fort Bliss.
- Hard, R. J., and R. Mauldin
1986 Modeling Prehistoric Land Use: An Example from West Texas and Southern New Mexico. Manuscript on file at Environmental Protection Office (ATZC-DEH), Fort Bliss, Texas.
-

Hard, R. J., and W. L. Merrill

1992 Mobile Agriculturalists and the Emergence of Sedentism: Perspectives from Northern Mexico. *American Anthropologist* 94:601-620.

Hard, R. J., R. Mauldin, and G. Raymond

1995 Mano Size, Stable Isotope Ratios, and Macrobotanical Remains as Indicators of Maize Dependence in the American Southwest. Manuscript in possession of the authors.

Hard, R. J., P. Graeber, J. Manasco, C. Tennis, and K. Thuesen

1994 Dona Ana Phase Ceramics and Cultural Evolution in the Southern Jornada Mogollon. *Bulletin of the Texas Archaeological Society* 62:267-283.

Harden, J. W.

1982 A quantitative index of soil development from field descriptions: Examples from a chronosequence in central California. *Geoderma* 28:1-28.

Hardie, C. H.

1958 The Pennsylvanian rocks of the northern Hueco Mountains. *West Texas Geological Society, Guidebook to Hueco Mountains*, pp. 43-45.

Harmon, R. S., D. C. Ford, and H. P. Schwarcz

1977 Interglacial Chronology of the Rocky and Mackenzie Mountains Based on ²³⁰Th and ²³⁴U Dating of Calcite Speleothems. *Canadian Journal of Earth Science* 14:2543-2552.

Harris, A. H.

1989 The New Mexican Late Wisconsin East versus West. *National Geographic Research* 5:205-217.

1990 Fossil evidence bearing on southwestern mammalian biogeography. *Journal of Mammalogy* 71:219-229.

Harris, M.

1979 *Cultural Materialism*. Random House, New York.

Harry, K. G.

1994 Cation-ratio dating of varnished artifacts: testing the assumptions. *American Antiquity* 60(1):118-130.

Haury, E.

1936 *The Mogollon Culture of Southwestern New Mexico*. Medallion Papers No. 20. Gila Pueblo, Globe, Arizona.

Hawley, J. W.

1965 Geomorphic surfaces along the Rio Grande valley from El Paso, Texas, to Caballo Reservoir, New Mexico. *New Mexico Geological Society, Guidebook 16th Field Conference*, pp. 188-198.

1969 Notes on the geomorphology and late Cenozoic geology of northwestern Chihuahua. *New Mexico Geological Society, Guidebook 20th Field Conference*, pp. 131-142.

1975 Quaternary history of the Dona Ana County region, south-central New Mexico. *New Mexico Geological Society, 26th Annual Field Conference Guidebook*, Las Cruces Country, pp. 139-150.

-
- 1981 Pleistocene and Pliocene history of the International Boundary area, southern New Mexico. In *Geology of the Border, Southern New Mexico-Northern Chihuahua*. El Paso Geological Society, Field Trip Guidebook, pp. 26-32.
- Hawley, J. W., G. O. Bachman, and K. Manley
1976 Quaternary stratigraphy in the Basin and Range and Great Plains provinces, New Mexico and western Texas. In *Quaternary Stratigraphy of North America*, edited by W. C. Mahaney. Stroudsburg, Pennsylvania: Dowden, Hutchinson, and Ross, pp. 235-274.
- Hawley, J. W., F. E. Kottslowski, W. R. Seager, W. E. King, W. S. Strain, and D. V. LeMone
1969 The Santa Fe Group in the South-Central New Mexico Border Region. In *Border Stratigraphy Symposium*, edited by F. E. Kottslowski and D. V. LeMone. New Mexico Bureau of Mines and Mineral Resources, Circular 104, pp.52-76.
- Hayden, B.
1987 Past to Present Uses of Stone Tools and Their Effects on Assemblage Characteristics in the Maya Highlands. In *Lithic Studies Among the Contemporary Highland Maya*, B. Hayden, editor. The University of Arizona Press, Tucson.
- Hays, P. D., and E. I. Grossman
1991 Oxygen isotopes in meteoric calcite cements as indicators of continental paleoclimate. *Geology* 19:441-444.
- Heaton, T. H. E.
1987 The $^{15}\text{N}/^{14}\text{N}$ ratios of plants in South Africa and Namibia: Relationship to climate and coastal/saline environments. *Oecologia* 74:236-246.
- Henry, C. D., and J. G. Price
1985 *Summary of the tectonic development of Trans-Pecos Texas*. The University of Texas at Austin, Bureau of Economic Geology Miscellaneous Map No. 36.

1989 Characterization of the Trans-Pecos region, Texas: geology. In *Studies of Geology and Hydrology in the Basin and Range Province, Southwestern United States, for Isolation of High-Level Radioactive Waste--Basis of Characterization and Evaluation of the Trans-Pecos Region, Texas*, edited by M. S. Bedinger, K. A. Sargent, and W. H. Langer. U.S. Geological Survey Professional Paper 1370-B, pp. B4-B22.
- Henry, C. D., and F. W. McDowell
1986 Geochronology of magnetism in the Tertiary volcanic field, Trans-Pecos Texas. In *Igneous Geology of Trans Pecos Texas--Field Trip Guide and Research Articles*, edited by J. G. Price, C. D. Henry, D. F. Parker, and D. S. Barker. The University of Texas, Bureau of Economic Geology Guidebook 23:99-122.
- Henry, C. D., F. W. McDowell, J. G. Price, and R. C. Smyth
1986 *Compilation of potassium-argon ages of Tertiary intrusive rocks, Trans-Pecos Texas*. The University of Texas, Bureau of Economic Geology Geological Circular 86-2.
- Herrick, C. L.
1904 Lake Otero, an ancient salt lake in southeastern New Mexico. *American Geologist* 34:174-189.
- Hester, T. R. (editor)
1977 *An Archeological Survey of the Radium Springs Area, Southern New Mexico, Archeological Survey Report, No. 26*. Center for Archeological Research, University of Texas at San Antonio.
-

Hill, D. V.

1988 Petrographic Analysis of Loop 375 Ceramics (Phase II). In *Loop 375 Archaeological Project Fort Bliss Maneuver Area I, El Paso County, Texas*. Appendix H. University of Texas at El Paso.

1989 Preliminary Ceramic Analysis for Loop 375. In *Interim Report for Phase II Additional Testing and Recommendations for Phase III Data Recovery, Loop 375 Data Recovery Project, El Paso County, Texas*. University of Texas at El Paso.

1993 The Ceramics of Todsen Cave, in Preliminary Investigations of the Archaic. In *The Region of Las Cruces, New Mexico*, edited by R. S. MacNeish. Historic and Natural Resources Report No. 9, Cultural Resources Management Branch, Directorate of Environment, United States Army Air Defense Artillery Center, Fort Bliss, Texas.

Hitchcock, R. K.

1982 *The Ethnoarcheology of Sedentism: Mobility Strategies and Site Structure Among Foraging and Food Producing Populations in the Eastern Kalahari Desert*. Ph.D. dissertation, University of New Mexico. University Microfilms, Ann Arbor, Michigan.

Hoffer, J. M.

1969 Geology and petrography of the campus andesite pluton, El Paso County, Texas. In *Guidebook of the Border Region*, edited by D. A. Córdoba, S. A. Wengerd, and J. Shomaker. New Mexico Geological Society, 20th Field Conference, pp. 102-107.

Hoffer, R. L.

1976 *Contact metamorphism of the Precambrian Castner Marble, Franklin Mountains, El Paso County, Texas*. Unpublished M.S. thesis, University of Texas at El Paso, 77 pp.

Hofman, J. L., L. C. Todd, and M. B. Collins

1991 Identification of Central Texas Edwards Chert at the Folsom and Lindenmeir Sites. *Plains Anthropologist* 36(137):297-308.

Holloway, R. G.

1981 *Preservation and experimental diagenesis of the pollen exine*. Unpublished Ph.D. dissertation, Texas A & M University, College Station.

1994a Pollen and Flotation Analysis of Samples From 16 Archaeological Sites, The Small Sites Project, Ft. Bliss Military Reservation, El Paso County, Texas. In *Small Sites in the Central Hueco Bolson; A Final Report on Project 90-11*. By Mauldin, R. P., T. B. Graves, and M. Bentley. Historic and Natural Resources Report Series, Archaeology Branch, Directorate of Environment, U.S. Army Air Defense Artillery Center, Fort Bliss, Texas.

1994b Flotation Analysis from 62 sites from the Hueco Mountain Project, Fort Bliss, Texas. Manuscript on file, Environmental Management Office, Fort Bliss.

Hooke, R. LeB.

1967 Processes on arid-region alluvial fans. *Journal of Geology* 75:438-460.

1990 Discussion of Use of Multiparameter Relative-Age Methods for Age Estimation and Correlation of Alluvial Fan Surfaces on a Desert Piedmont, Eastern Mojave Desert, California. *Quaternary Research* 34(2):262.

Horowitz, A., R. E. Gerald, and M. S. Chaiffetz

1981 Preliminary Paleoenviromental Implications of Pollen Analyzed from Archaic, Formative, and Historic Near El Paso, Texas. *Texas Journal of Science* 23:61-72.

Horsfall, G.

1987 A Design Theory Perspective on Variability in Grinding Stones. In *Lithic Studies Among the Contemporary Highland Maya*, edited by B. Hayden, pp. 332-377. The University of Arizona Press, Tucson.

Howard, V. W., J. L. Holechek, R. D. Pieper, K. Gee-Hammond, M. Cardenas, and S. L. Beasom

1990 *Habitat Requirements for Pronghorn on Rangeland Impacted by Livestock and Net Wire in Eastcentral New Mexico*. Agricultural Experimental Station Report 750, College of Agriculture and Home Economics, New Mexico State University, Las Cruces.

Hubbard, R. A.

1987 *Prehistoric agricultural fields and water control systems of south-central New Mexico*. Unpublished M.A. thesis, the University of Texas at Austin.

Huebner, J. A.

1991a Late Prehistoric bison populations in Central and southern Texas. *Plains Anthropologist* 36(137):343-358.

1991b Cactus for dinner again! An isotopic analysis of Late Archaic diet in the Lower Pecos Region of Texas. In *Papers on Lower Pecos Prehistory*, edited by S. A. Turpin, pp. 175-190. Studies in Archeology 8, Texas Archeological Research Laboratory, The University of Texas at Austin.

Human Systems Research

1973 Technical Manual; 1973 Survey of the Tularosa Basin. Human Systems Research, Three Rivers, New Mexico.

Hunt, C. B.

1967 *Physiography of the United States*. W. H. Freeman. San Francisco, California.

Huntley, D. J., D. I. Godfrey-Smith, and M. L. W. Thewalt

1985 Optical dating of sediments. *Nature* 313:105-107.

Hurford, A. J., and P. F. Green

1982 A user's guide to fission track dating calibration. *Earth and Planetary Science Letters* 59:343-354.

Hurst, V. J., and A. R. Kelley

1961 Patination of cultural flints. *Science* 134:251-256.

Hutt, G., and J. Jaek

1989 Infrared stimulated photoluminescence dating of sediments. *Ancient TL* 7:48-51.

Hyland, D. C., J. M. Tersak, J. M. Adovasio, and M. I. Siegel

1990 Identification of the Species of Origin of Residual Blood on Lithic Material. *American Antiquity* 55:104-112.

Ichikawa, Y.

1965 Dating of ancient ceramics by thermoluminescence. *Bulletin of the Institute for Chemical Research* 43:1-6. Kyoto University.

Ikeya, M.

- 1985 Dating Methods of the Pleistocene and their Problems: IX. Electron Spin Resonance. In *Dating Methods of the Pleistocene and their Problems*, reprinted with revisions from a series of papers in Geoscience Canada, 1978-1982, edited by N. W. Rutter, pp. 73-87. Geoscience Canada, Reprint Series 2.

Ikeya, M., and T. Miki

- 1980 Electron-spin resonance dating of animal and human bones. *Science* 207:977-979.

Irwin-Williams, C.

- 1973 The Oshara Tradition: Origins of Anasazi Culture. *Eastern New Mexico University Contributions in Anthropology* 5(1). Eastern New Mexico University, Portales.

Irwin-Williams, C.

- 1979 Post-Pleistocene Archaeology 7000-2000 B.C. In *Handbook of North American Indians*, Volume 9, Southwest, edited by A. Ortiz, pp. 33-42. Smithsonian Institution, Washington, D.C.

Jaco, H. B.

- 1971 *Soil Survey of El Paso County, Texas*. Washington: U. S. Department of Agriculture, Soil Conservation Service.

Jacobs, M., V. Hardner, and R. K. Graham

- 1979 Oil, gas, and coal resource inventory, Las Cruces District, Sacramento ES Area. Open File Report, U. S. Bureau of Land Management, Las Cruces.

Jacoby, G. C. (editor)

- 1980 *Proceedings of the International Meeting on Stable Isotopes in Tree-Ring Research*. Carbon Dioxide Effects Research and Assessment Program. Washington, D. C., U.S. Department of Energy.

Jenny, H.

- 1941 *Factors of Soil Formation*. McGraw-Hill, New York.

Jobson, R. W.

- 1986 Stone Tool Morphology and Rabbit Butchering. *Lithic Technology* 15:9-20.

Jochim, M. A.

- 1976 *Hunter-Gatherer Subsistence and Settlement: A Predictive Model*. Academic Press, New York.

- 1991 Archaeology as Long-Term Ethnography. *American Anthropologist* 93:308-321.

Johnson, M. D.

- 1989 *Optimal Foraging Theory and Mescalero Apache Dietary Maximization: Implications for Hunter-Gatherer Settlement Patterns*. Unpublished M.A. thesis, New Mexico State University, Las Cruces.

Johnson, M. D., and S. Upham

- 1988 Approaches To Adaptive Diversity: A Preliminary Report On Archeological Investigations In The Organ Mountains, Southern New Mexico. In *Fourth Jornada Mogollon Conference (October 1985) Collected Papers*, edited by M. S. Duran and K. W. Laumbach, pp. 65-92. Human Systems Research, Tularosa, New Mexico.
-

Jones, G. T., D. K. Grayson, and C. Beck

1983 Artifact Class Richness and Sample Size in Archaeological Surface Assemblages. In *LuLu Linear Punctated: Essays in Honor of George Irving Quimby*, edited by R. C. Dunnell and D. K. Grayson, pp. 53-73. Anthropological Papers No. 72. Museum of Anthropology, University of Michigan, Ann Arbor.

Jones, P. R.

1980 Experimental Butchery with Modern Stone Tools and its Relevance for Palaeolithic Archaeology. *World Archaeology* 12(2):153-165.

Jones, R. C.

1990 *Analysis of a Lithic Sample, Fresnal Rock Shelter, Southcentral New Mexico*. Unpublished M.A. thesis, Eastern New Mexico University, Portales.

Katzenberg, M. A., and J. H. Kelley

1991 Stable Isotope Analysis of Prehistoric Bone From the Sierra Blanca Region of New Mexico. In *Proceedings of the 1988 Mogollon Conference*, P. Beckett, editor. COAS Books, Las Cruces, New Mexico.

Kauffman, B.

1984 The Vista Hills Site: Eight Thousand Years at the Edge of the Hueco Bolson. *The University Museum, New Mexico State University, Occasional Papers No. 11, Cultural Resource Management Division Report No. 563*, Las Cruces.

Kauffman, B., and D. Batcho

1983 Ephemeral Sites and Resilient Folks: A Discussion and Analysis of Seven Archaeological Sites near Las Cruces, New Mexico, Tested as Part of the Eleno Gallegas Land Exchange. Manuscript, of file, Cultural Resources Management Division, Las Cruces.

1988 Final Report Of Archeological Investigations Along El Paso Electric Company's 345 KV Caliente-Newman-Amrad Transmission System On Fort Bliss, Texas. *Natural Resources Report No. 4*, Directorate of Engineering and Housing, Environmental Management Office, Fort Bliss.

Keeley, L. H.

1980 *Experimental Determination of Stone Tool Use*. University of Chicago Press. Chicago, Illinois.

Keene, A. S.

1979 Economic Optimization Models and the Study of Hunter-Gatherer Subsistence Settlement Systems. In *Transformations: Mathematical Approaches to Culture Change*, edited by Colin Renfrew and K Cooke, pp. 369-404. Academic Press.

Kegley, G.

1982 *Archaeological Investigations at Hueco Tanks State Historical Park, El Paso County, Texas*. Texas Parks and Wildlife Department, Parks Division, Interpretation and Exhibits Branch, Austin.

Kelley, J. C.

1984 The Archeology of the Sierra Blanca Region of Southeastern New Mexico. *Anthropological Papers No. 74*, Museum of Anthropology, University of Michigan, Ann Arbor.

1986 Jumano and Patarabueye, Relations at La Junta de Los Rios. *Anthropological Papers*, Museum of Anthropology, University of Michigan, No. 77.

Kelley, J. H.

1991 An Overview of the Capitan North Project. In *Mogollon V* pp. 166-176, COAS Publishing and Research, Las Cruces, New Mexico.

Kelly, E. F., R. G. Amundson, B. D. Marino, and M. J. DeNiro

1991 Stable isotope ratios of carbon in phytoliths as a quantitative method of monitoring vegetation and climate change. *Quaternary Research* 35(2):222-233.

Kelly, R. L.

1985 *Hunter-Gatherer Mobility and Sedentism: A Great Basin Study*. Ph.D. dissertation, Department of Anthropology, University of Michigan. University Microfilms, Ann Arbor.

Kelly, T. C.

1977 The High Lonesome Bead Cache. In *An Archeological Survey of the Radium Springs Area, Southern New Mexico*, edited by T. R. Hester. Archeological Survey Report, No. 26. Center for Archeological Research, University of Texas at San Antonio.

Kenmotsu, N. A.

1994 *Helping Each Other Out, A Study of the Mutualistic Relations of Small Scale Foragers and Cultivators in La Junta de Los Rios Region, Texas and Mexico*. Unpublished Ph.D. dissertation, The University of Texas at Austin.

Kenmotsu, R. D.

1977 The botanical research. In *A Cultural Resource Inventory and Assessment of McGregor Guided Missile Range, Otero County, New Mexico, Part III: Botanical and Geological Studies*. University of Texas at Austin, Texas Archeological Survey, Research Report 65, Part III. pp. 3-93.

Kenmotsu, R. D., and J. D. Pigott

1977 *A Cultural Resources Inventory and Assessment of McGregor Guided Missile Range, Otero County, New Mexico, Part III. Botanical and Geological Studies*. Texas Archeological Survey, Research Report No. 65:III. The University of Texas at Austin.

Kennedy, G. C., and L. Knopff

1960 Dating by thermoluminescence. *Archaeology* 13:147-148.

Khresat, S. A.

1993 Geomorphic investigation of a possible paleolake on McGregor Range. In *Soil-Geomorphic and Paleoclimatic Characteristics of the Fort Bliss Maneuver Areas, Southern New Mexico and Western Texas*, edited by H. C. Monger, pp. 35-67, Historic and Natural Resources Report 10, Cultural Resources Management Program, Directorate of the Environment, United States Army Air Defense Artillery Center, Fort Bliss, Texas.

Kidder, A. V.

1927 Southwestern Archaeological Conference. *Science* 68:489-491.

1962 *An Introduction to the Study of Southwestern Archaeology (revised edition)*. Yale University press, New Haven, Connecticut.

Kingston, M.

1986 *Texas Almanac, Sesquicentennial Edition*. Dallas Morning News.

Kintigh, K.

1989 Sample Size, Significance, and Measures of Diversity. In *Quantifying Diversity in Archaeology*, edited by R. D. Leonard and G. T. Jones, pp. 25-26. Cambridge University Press.

Kirch, Patrick V.

1980 The Archaeological Study of Adaptation: Theoretical and Methodological Issues. *Advances in Archaeological Method and Theory* 3:101-156, edited by M. B. Schiffer. Academic Press.

Knowles, D. B., and R. A. Kennedy

1956 Ground-Water Resources of the Hueco Bolson, Northeast of El Paso, Texas. *Texas Water Board of Engineers, Bulletin 5615*.

Kocurek, G.

1981 Significance of interdune deposits and bounding surfaces in aeolian dune sands. *Sedimentology* 28:753-780.

Kocurek, G., and J. Nielsen

1986 Conditions favorable for the formation of warm-climate aeolian sand sheets. *Sedimentology* 33:795-816.

Kottlowski, F. E.

1958 Geologic history of the Rio Grande near El Paso. In *Guide Book 1958 Field Trip, Franklin and Hueco Mountains*, edited by L. A. Nelson and B. R. Haigh, pp. 46-54. Midland: West Texas Geological Society.

1969 Summary of Late Paleozoic in El Paso Border Region. In *Border Stratigraphy Symposium*, edited by F. E. Kottlowski and D. V. LeMone. New Mexico Bureau of Mines and Mineral Resources, Circular 104, pp. 38-51.

1975 Stratigraphy of the San Andres Mountains in south-central New Mexico. In *Guidebook of the Las Cruces Country*, edited by W. R. Seager, R. E. Clemons, J. F. Callender. New Mexico Geological Society, Guidebook 26th Field Conference, pp. 95-104.

Kroeber, A.

1925 Handbook of the Indians of California. *Bureau of American Ethnology, Bulletin 78*. Washington, D.C.

Krone, M.

1975 A Report on Folsom Points in the El Paso Area. *The Artifact* 13 (4):1-19. El Paso Archaeological Society, El Paso, Texas.

Krueger, H. W., and C. Sullivan

1984 Models for Carbon Isotope Fractionation Between Diet and Bone. In *Stable Isotopes in Nutrition*, J. R. Turnlund and P. E. Johnson, editors. ACS Symposium Series 228, American Chemical Society, Washington D.C.

Ku, T.-L., and Z.-C. Liang

1984 The dating of impure carbonates with decay-series isotopes. *Nuclear Instruments and Methods in Physics Research* 223:563-571.

Ku, T.-L., W. B. Bull, S. T. Freeman, and K. G. Knauss

1979 Th230-U234 dating of pedogenic carbonates in gravelly desert soils of Vidal Valley, southeastern California. *Geological Society of America Bulletin* 90(I):1063-1073.

-
- Kurz, M. D., and E. J. Brook
1994 Surface exposure dating with cosmogenic nuclides. In *Dating in Exposed and Surface Contexts*, edited by C. Beck, pp. 139-159.
- Kutzbach, J. E.
1983 Modeling of Holocene Climates. In *Late Quaternary Environments of the United States, Volume 2: The Holocene*, edited by H. E. Wright, Jr., pp. 271-277.
- Kutzbach, J. E., and W. F. Ruddiman
1993 Model description, external forcing, and surface boundary conditions. In *Global Climates Since the Last Glacial Maximum*, edited by H. E. Wright, Jr., J. E. Kutzbach, T. Webb III, W. F. Ruddiman, F. A. Street-Perrott, and P. J. Bartlein, pp. 12-23. Minneapolis: University of Minnesota Press.
- Kutzbach, J. E., P. J. Guetter, P. J. Behling, and R. Selin
1993 Simulated climatic changes: results of the COHMAP climate-model experiments. In *Global Climates Since the Last Glacial Maximum*, edited by H. E. Wright, Jr., J. E. Kutzbach, T. Webb III, W. F. Ruddiman, F. A. Street-Perrott, and P. J. Bartlein, pp. 24-93. Minneapolis: University of Minnesota Press.
- Lancaster, J.
1983 *An Analysis of Manos and Metates From the Mimbres Valley, New Mexico*. Unpublished M.A. thesis, Department of Anthropology, The University of New Mexico, Albuquerque.
- Lancaster, N.
1994 Dune morphology and dynamics. In *Geomorphology of Desert Environments*, edited by Abrahms, A. D., and A. J. Parsons, pp. 474-505. Chapman and Hall, London.
- Lancaster, N., and W. G. Nickling
1994 Aeolian sediment transport. In *Geomorphology of Desert Environments*, edited by Abrahms, A. D., and A. J. Parsons, pp. 447-473. Chapman and Hall, London.
- Laumbach, K.
1980 Lithic Artifacts. In *Prehistory and History of the Ojo Amarillo: Archaeological Investigations of Block II, Navajo Indian Irrigation Project, San Juan County, New Mexico, Volume III*, edited by D. Kirkpatrick, pp. 849-958. Cultural Resource Management Division, New Mexico State University, Las Cruces.
- Lauritzen, S-E., J. E. Haugen, R. L'vlie, and H. Gilje-Nielsen
1994 Geochronological potential of isoleucine epimerization in calcite speleothems. *Quaternary Research* 41:52-58.
- Laville, H.
1976 Deposits in calcareous rockshelters: Analytical methods and climatic interpretations. In *Geoarchaeology: Earth Sciences and the Past*, edited by D. A. Davidson and M. L. Shackley, pp. 137-155. Duckworth, London.
- Laville, H., J. P. Rigaud, and J. Sackett
1980 *Rock Shelters of the Perigord: Geological Stratigraphy and Archaeological Succession*. Academic Press, New York.
- Leach, J. D.
1993 Hot Rocks in the Sand. Paper presented at the 8th Jornada-Mogollon Conference, Tularosa, New Mexico.
-

-
- 1994 Archaeological Investigations in the Eastern Hueco Bolson: Preliminary Findings from the Hueco Mountain Archaeological Project. In *Mogollon VII: The Collected Papers of the 1992 Mogollon Conference held in Las Cruces, New Mexico*. COAS Publishing and Research.
- Leach, J. D., and M. E. Newman
1994 Immunological Residue Analysis: The Hidden Evidence From Meyer Pithouse Village. Manuscript on file, University of Texas at El Paso.
- Leach, J. D., and R. P. Mauldin
n.d. Experimental and Archaeological Residue Analysis Conducted on Fort Bliss. Manuscript in preparation.
- Leach, J. D., F. A. Almaraz, and K. Adkins
1993 The Hueco Mountain Archaeological Project: Discussions on Survey, Surface Collection, and Subsurface Testing. Paper presented at the 7th Jornada Mogollon Conference, Tularosa, New Mexico.
- Leach, J. D., F. A. Almaraz, B. Buck, and G. R. Burgett
1993 The Hueco Mountain Reservoir: A preliminary assessment of an El Paso Phase water catchment basin. *The Artifact* 31(2):33-45.
- Leach, J. D., C. H. Monger, and R. Mauldin
1994 Eolian Geomorphology, Survey Intensity, and Landscape Patterning in the Surface Archaeological Record. Paper presented at the 8th Mogollon Conference, El Paso, Texas.
- Leach, J. D., R. Holloway, and F. Almaraz
n.d. Prehistoric Evidence for the use of *Chenopodium* (Goosefoot) From the Hueco Bolson, Texas. Manuscript submitted to the Texas Journal of Science, 1995.
- Lee, R. B.
1968 What Hunters Do for a Living, or, How to Make Out on Scarce Resources. In *Man the Hunter*, pp. 30-48, edited by R. B. Lee and I. DeVore. Aldine.
- 1972 The !Kung Bushmen of Botswana. In *Hunters and Gatherers Today A Socioeconomic Study of Eleven Such Cultures in the Twentieth Century*, edited by M. G. Bicchieri, pp. 327-368. Holt, Rinehart and Winston, New York.
- 1976 !Kung Spatial Organization: An Ecological and Historical Perspective. In *Kalahari Hunter-Gatherers Studies of the !Kung San and Their Neighbors*, edited by R. B. Lee and I. DeVore. Harvard University Press, Cambridge, Massachusetts.
- 1979 The !Kung San: Men, Women, and Work. In *A Foraging Society*. Cambridge University Press, Cambridge.
- 1984 *The Dobe !Kung*. Holt, Rinehart and Winston, New York.
- Leggat, R. E., M. E. Lowry, and J. W. Hood
1963 Ground-water resources of the lower Mesilla Valley, Texas and New Mexico. *U.S. Geological Survey, Water-Supply Paper 1669AA*.
- Lehmer, D. J.
1948 The Jornada Branch of the Mogollon. *University of Arizona, Social Science Bulletin No. 17*. University of Arizona, Tucson.
-

LeMone, D. V.

1969a Lower Paleozoic rocks in the El Paso area. In *Guidebook of the Border Region*, D. A. Córdoba, S. A. Wengerd, and J. Shomaker. New Mexico Geological Society, 20th Field Conference, pp. 68-79.

1969b Cambrian-Ordovician in El Paso Border Region. In *Border Stratigraphy Symposium*, edited by F. E. Kottowski and D. V. LeMone. New Mexico Bureau of Mines and Mineral Resources, Circular 104, pp. 17-25. Socorro: New Mexico Institute of Mining and Technology.

1982 *Stratigraphy of the Franklin Mountains, El Paso County, Texas and Doña Ana County, New Mexico*. El Paso Geological Society, Symposium on the Franklin Mountains, pp. 42-72.

1989 Stratigraphy and Structure of the Franklin Mountains, West Texas. In *Structure and Stratigraphy of Trans-Pecos Texas*. 28th International Geological Congress, Field Trip Guidebook T317:55-64.

LeMone, D. V., and W. C. Cornell

1988 *Franklin Mountains, Texas and New Mexico*. El Paso Geological Society and American Association of Petroleum Geologists, Stratigraphy Field Guide, 43 pp.

Leonard, A. B., and J. C. Frye

1975 *Pliocene and Pleistocene deposits and molluscan faunas, east-central New Mexico*. New Mexico Bureau of Mines and Mineral Resources, Memoir 30.

Leonard, R. D., and G. Jones

1989 *Quantifying Diversity in Archaeology*. Cambridge University Press, New York.

Leopold, B. D., and P. R. Krausman

1991 Factors Influencing Desert Mule Deer Distribution and Productivity in Southwestern Texas. *The Southwestern Naturalist* 36:67-74.

Leopold, L. B., E. B. Leopold, and F. Wendorf

1963 Some climatic indicators in the period A. D. 1200-1400 in New Mexico. In *Changes of Climate: Proceedings of the Rome Symposium*, organized by Unesco and the World Meteorological Organization, pp. 265-270.

Libby, W. F.

1955 *Radiocarbon Dating*. University of Chicago Press. Chicago, Illinois.

Linton, R.

1944 North American Cooking Pots. *American Antiquity* 9:369-380.

Linse, A. R.

1993 Geoarchaeological Scale and Archaeological Interpretation: Examples from the Central Jornada Mogollon. In *Effects of Scale on Archaeological and Geoscientific Perspectives*, edited by J. K. Stein and A. R. Linse, pp. 11-28. The Geological Society of America, Boulder, Colorado.

Longacre, W. A. (editor)

1991 *Ceramic Ethnoarchaeology*. The University of Arizona Press, Tucson.

Lowe, J. J., and M. J. C. Walker

1994 *Reconstructing Quaternary Environments*. Longman, London.

Lowenstein, J. M.

1985 Molecular Approaches to the Identification of Species. *American Scientist* 73:541-547.

Lovejoy, E. M. P.

1975 An interpretation of the structural geology of the Franklin Mountains, Texas. In *Guidebook of the Las Cruces Country*, edited by W. R. Seager, R. E. Clemons, and J. F. Callender, pp 261-268. New Mexico Geological Society Guidebook, 26th Field Conference.

Loy, T. H.

1993 The artifact as site: an example of the biomolecular analysis of organic residues on prehistoric tools. *World Archaeology* 25 No. 1, pp. 44-63.

Lozinsky, R. P., and P. W. Bauer

1991 Structure and basin fill units of the Tularosa Basin. In *Geology of the Sierra Blanca, Sacramento, and Capitan Ranges, New Mexico*, edited by J. M. Barker, B. S. Kues, G. S. Austin, and S. G. Lucas. New Mexico Geological Society 42nd Annual Field Conference, pp. 7-11.

Luckman, B., and J. Gray

1990 Oxygen isotope ratios from tree rings containing compression wood. *Quaternary Research* 33:117-121.

Lundelius, E. L.

1986 Vertebrate paleontology of the Balcones Fault trend. In *The Balcones Escarpment: Geology, Hydrology, Ecology, and Social Development in Central Texas*, edited by P. L. Abbott and C. M. Woodruff, pp. 41-50. Comet Reproduction Services, Sante Fe Springs, California.

Lustig, L. K.

1965 Clastic sedimentation in Deep Springs Valley, California. *U. S. Geological Survey Professional Paper* 352-F, pp. 131-190.

Lyman, R. L.

1984 Bone Density and Differential Survival of Fossil Classes. *Journal of Anthropological Archaeology* 3:259-299.

1993 Density-Mediated Attrition of Bone Assemblages: New Insights. In *From Bones to Behavior*, edited by J. Hudson, pp. 324-340. Occasional Paper No. 21, Center for Archaeological Investigations, Southern Illinois University, Carbondale.

Mabbutt, J. A.

1977 *Desert Landforms*. Australian National University Press. Canberra.

Machette, M. N.

1985 Calcic soils of the Southwestern United States. In *Soils and Quaternary Geology of the Southwestern United States*, edited by D. L. Weide. Geological Society of America Special Paper 203(1-21).

1987 Dating Quaternary faults in the southwestern United States using buried calcic paleosols. *U.S. Geological Survey Journal of Research* 6(3):369-381.

MacNeish, R. S. (editor)

1993 *Preliminary Investigations of the Archaic in the Region of Las Cruces, New Mexico*. Edited by Richard S. MacNeish. Historic and Natural Resources Report No. 9, Cultural Resources Management Branch, Directorate of Environment, United States Army Air Defense Artillery Center, Fort Bliss, Texas.

MacNeish, R. S., and P. H. Beckett

1987 *The Archaic Chihuahua Tradition*. COAS Monograph No. 7.

MacNeish, R. S., and B. Marino

1993 Carbon 13/12 and Nitrogen 15/14 Isotope Ratios in Skeletons from the Jornada Area. In *Preliminary Investigations of the Archaic in the Region of Las Cruces, New Mexico*. Edited by Richard S. MacNeish, pp. 117-122. Historic and Natural Resources Report No. 9, Cultural Resources Management Branch, Directorate of Environment, United States Army Air Defense Artillery Center, Fort Bliss, Texas.

MacNeish, R. S., G. Cunnar, G. Jessop, and P. Wilner

1993 *A Summary of the Paleo-Indian Discoveries in Pendejo Cave near Orogrande, New Mexico*. Andover Foundation for Archaeological Research, Andover, Massachusetts.

Magaritz, M.

1983 Carbon and oxygen isotope composition of recent and ancient coated grains. In *Coated Grains*, edited by T. M. Peryt. Berlin: Springer Verlag.

Mallouf, R. J.

1985 *A Synthesis of Eastern Trans-Pecos Prehistory*. Unpublished M.A. thesis, Department of Anthropology, The University of Texas at Austin.

Mandel, R. D.

1987 Late Quaternary environments of the Great Plains: implications for cultural resource management. In *Kansas Prehistoric Archaeological Preservation Plan*, edited by K. L. Brown and A. H. Simmons. Lawrence, Kansas. Office of Archaeological Research of the Museum of Anthropology, University of Kansas.

Marchbanks, M. L.

1989 *Lipid Analysis in Archaeology: An Initial Study of Ceramics and Subsistence at the George C. Davis Site*. Unpublished M.A. thesis, University of Texas at Austin.

Markgraf, V., J. P. Bradbury, R. M. Forester, G. Singh, and R. S. Sternberg

1984 San Agustin Plains, New Mexico: Age and paleoenvironmental potential reassessed. *Quaternary Research* 22:336-343.

Marks, M. K., J. C. Rose, and E. L. Buie

1985 Bioarchaeology of Seminole Sink. In *Seminole Sink: Excavation of a Vertical Shaft Tomb, Val Verde County, Texas*, edited by S. A. Turpin, pp. 99-152. Research Report 93, Texas Archeological Survey, The University of Texas at Austin.

Marshal, M.

1973 The Jornada Culture Area. In *Human Systems Research Technical Manual: 1973 Survey of the Tularosa Basin*. Human Systems Research. Tularosa, New Mexico.

Marston, R. A.

1986 Maneuver-caused wind erosion impacts, south-central New Mexico. In *Aeolian Geomorphology*, edited by W. G. Nickling. Proceedings of the 17th Annual Binghampton Geomorphology Symposium, September 1986, pp. 273-290. Allen and Unwin, Boston.

Martel, Y. A., and E. A. Paul

1974 The use of the radiocarbon dating of organic matter in the study of soil genesis. *Soil Science Society of America Proceedings* 38:501-506.

Martin, P. S.

1943 The SU Site, Excavations at a Mogollon Village, Western New Mexico, Second Season, 1941. *Fieldiana Anthropology* 32(2). Chicago, Illinois.

Martin, P. S., and J. B. Rinaldo

1947 The SU site, excavations at a Mogollon Village, western New Mexico: 3rd Season, 1946. *Fieldiana Anthropology* 32 (3).

Martin, P. S., and F. Plog

1973 *The Archaeology of Arizona*. Doubleday-Natural History Press, New York.

Mathien, F. J.

1992 Exchange Systems and Social Stratification Among the Chaco Anasazi. In *The American Southwest and Mesoamerica: Systems of Prehistoric Exchange*, edited by J. E. Ericson and T. G. Baugh, pp. 27-63. Plenum Press, New York.

1995 Evidence of Prehistoric Turquoise Mining at Orogrande, Jarilla Mountains, New Mexico. In *Of Pots and Rocks, Papers in Honor of A. Helene Warren*, edited by M. S. Duran and D. T. Kirkpatrick, The Archaeological Society of New Mexico 21.

Matson, D. S., and A. H. Schroeder

1957 Cordero's Description of the Apache. *New Mexico Historical Review* 32(4)335-356. Historical Society of New Mexico and the University of New Mexico.

Matthews, J. A.

1980 Some problems and implications of C14 dates from a podzol buried beneath an end moraine at Haugabreen, Southern Norway. *Geografiska Annaler* 62A:185-208.

1985 Radiocarbon dating of surface and buried soils: principals, problems, and prospects. In *Geomorphology and Soils*, edited by K. S. Richards, R. R. Arnett, and S. Ellis, pp. 269-288. Allen and Unwin, London.

Mauldin, R.

1983 *An Inquiry into the Past: Basketmaker II Settlement on Northeastern Black Mesa, Arizona*. Unpublished M.A. thesis, The University of Texas at Austin.

1986 Settlement and Subsistence Patterns During the Pueblo Period on Fort Bliss, Texas: A Model. In *Mogollon Variability*, edited by C. Benson and S. Upham. The University Museum Occasional Papers, No. 15:225-270. New Mexico State University, Las Cruces.

1993a *The DIVAD Archaeological Project*. Historic and Natural Resources Report No. 8, Cultural Resources Management Program, Directorate of Environment, United States Army Air Defense Artillery Center, Fort Bliss, Texas.

1993b The Relationship between Ground Stone and Agricultural Intensification in Western New Mexico. *Kiva* 58:317-330.

1994 Small Sites in Western Texas and Southern New Mexico. *Bulletin of Texas Archaeology* 65:185-206.

1995 *Groping for the Past: Investigating Archaeological Patterns Across Space and Time in the Southern Southwestern United States*. Unpublished Ph.D. dissertation, Department of Anthropology, University of New Mexico, Albuquerque.

Mauldin, R. P., and T. B. Graves

- 1991 The Small Site Project on Ft. Bliss: A Summary of Phase I and II Results with Phase III Recommendations. Manuscript on file, Historic and Natural Resources Report Series, Archaeology Branch, Directorate of Environment, U.S. Army Air Defense Artillery Center, Fort Bliss.

Mauldin, R., and J. Leach

- 1994a Geomorphic Processes and Patterning in the Archaeological Record. Manuscript on file at Archaeology Branch, Directorate of Environment, U.S. Army Air Defense Artillery Center, Fort Bliss.

- 1994b Grinding Assemblages and Economic Patterns: An Example From the American Southwest. Paper presented at the 59th Annual Meeting of the Society for American Archaeology, Anaheim, California.

Mauldin, R., and B. L. O'Leary

- 1994 HAR-074 (LA 104,267), The Boles Wells Paleoindian Site Data Collection and Test Excavations Holloman Air Force Base, Otero County, New Mexico. *Human Systems Research Report No. HSR 9349E, HAFB Report No. 1994-021*. Human Systems Research, Tularosa, New Mexico.

Mauldin, R. P., and S. A. Tomka

- 1988 Informe preliminar sobre experimentos en el uso de moledoras de piedra (Khona) en la comunidad de Alota, Nor Lipez, Potosi, Bolivia. Manuscript submitted to the National Museum of Ethnography and Folklore, La Paz, Bolivia.

- 1989 An Ethnoarchaeological Assessment of Grinding Efficiency and Ground Stone Size. Paper presented at the 54th Annual Meeting of the Society for American Archaeology, Atlanta, Georgia.

Mauldin, R., T. Graves, and M. Bentley

- 1994 Small Sites in the Central Hueco Bolson, A Final Report on Project 90-11. Draft Report on file at Cultural Resources Management Branch, Directorate of Environment, Fort Bliss, Texas.

Mauldin, R., J. Leach, and D. S. Amick

- 1995 On the Identification of Blood Residues on Paleoindian Artifacts. Current Research in the Pleistocene. In press.

Mauldin, R., J. Leach, and H. C. Monger

- 1994 Eolian Geomorphology, Artifact Patterning, and Assemblage Composition. Paper presented at the 8th Mogollon Conference, El Paso, Texas.

Mauss, M.

- 1967 *The Gift: Forms and Functions of Exchange in Archaic Societies*. Translated by Ian Cunnison, The Norton Library, W.W. Norton, New York.

Mayer, L., R. Gerson, and W. B. Bull

- 1984 Alluvial gravel production and deposition--A useful indicator of Quaternary climatic changes in deserts (a case study in southwestern Arizona). In *Channel Processes--Water, Sediment, Catchment Controls*, edited by A. P. Schick, pp. 137-151. Catena Supplement 5.

McAnulty, W. N., Jr.

- 1967 *Geology of the Fusselman Canyon Area, Franklin Mountains, El Paso County, Texas*. Unpublished M.S. thesis, University of Texas at Austin, 79 pp.

McCartney, P. H., and M. F. Glass

- 1990 Simulation Models and the Interpretation of Archaeological Diversity. *American Antiquity* 55:521-536.
-

-
- McCoy, W. D.
1987 The precision of amino acid geochronology and paleothermometry. *Quaternary Science Reviews* 6:43-54.
- McFadden, L. D., S. G. Wells, and M. J. Jercinovich
1987 Influences of eolian and pedogenic processes on the origin and evolution of desert pavements. *Geology* 15:504-508.
- McFadden, L. D., J. B. Ritter, and S. G. Wells
1989 Use of Multiparameter Relative-Age Methods for Age Estimation and Correlation of Alluvial Fan Surfaces on a Desert Piedmont, Eastern Mojave Desert, California. *Quaternary Research* 32:276-290.
- McFadden, L. D., and P. L. K. Knuepfer
1990 Soil geomorphology: A linkage of pedology and surficial processes. *Geomorphology* 3:197-205.
- McGlasson, E. H.
1969 Siluro-Devonian of West Texas and Southeastern New Mexico. In *Border Stratigraphy Symposium*, edited by F. E. Kottowski and D. V. LeMone. New Mexico Bureau of Mines and Mineral Resources, Circular 104, pp. 26-37.
- McGuire, R. H.
1992 The Structure and Organization of Hohokam Exchange. In *The American Southwest and Mesoamerica: Systems of Prehistoric Exchange*, edited by J. E. Ericson and T. G. Baugh, pp. 95-119, Plenum Press, New York.
- Mehring, P. J., Jr.
1977 Great Basin late Quaternary environments and chronology. *Desert Research Institute Publications in the Social Sciences* 12:113-167.
- Meinzer, O. E., and R. E. Hare
1915 Geology and Water Resources of the Tularosa Basin, New Mexico. *U.S. Geological Survey, Water-Supply Paper* 343.
- McKee, E. D.
1966 Structures of dunes at White Sands National Monument, New Mexico. *Sedimentology* 7:1-69.
- McKee, E. D., and R. J. Moiola
1975 Geometry and growth of the White Sands dune field, New Mexico. *U.S. Geological Survey, Journal of Research* 3:59-66.
- Mello, V. M.
1977 *Density Trends, Some Life History Characteristics, and Morphology of Mule Deer in the Sacramento Mountains*. Unpublished M.S. thesis, New Mexico State University, Las Cruces.
- Melton, F. A.
1940 A tentative classification of sand dunes Its application to dune history in the Southern High Plains. *Journal of Geology* 48:113-174.
- Mera, H. P.
1931 *Chupadero Black-on-white*. Laboratory of Anthropology, Technical Series, No. 1. Museum of New Mexico, Santa Fe.
-

-
- 1938 Reconnaissance and Excavation in Southeastern New Mexico. *Memoirs of the American Anthropological Association No. 51*. Washington, D.C.
- 1943 An Outline of Ceramic Developments in Southern and Southeastern New Mexico. *Laboratory of Anthropology, Technical Series, No. 11*. Museum of New Mexico, Santa Fe.
- Mera, H. P., and Stallings
- 1931 Lincoln Black-on-red. *Laboratory of Anthropology, Technical Series, No. 2*. Museum of New Mexico, Santa Fe.
- Michaelis, J., E. Usdowski, and G. Menschel
- 1985 Partitioning of ^{13}C and ^{12}C on the Degassing of CO_2 and the Precipitation of Calcite: Rayleigh-type Fractionation and a Kinetic Model. *American Journal of Science* 285:318-327.
- Michalik, L., and D. Batcho
- 1988 Ceramic Analysis. In *Final Report Of Archeological Investigations Along El Paso Electric Company's 345 KV Caliente-Newman-Amrad Transmission System On Fort Bliss, Texas*. Batcho and Kauffman Associates, Cultural Resources Report Number 40 and Historic and Natural Resources Report Number 4, Directorate of Engineering and Housing, Environmental Management Office, Fort Bliss, Texas.
- Michels, J. W.
- 1973 *Dating Methods in Archaeology*. Seminar Press, New York.
- Mikkelsen, P.
- 1985 *A Study of Millingtool Form and Function Applied to the North Coast Ranges, California*. Unpublished M. A. thesis, Sonoma State University, Sonoma.
- Miller, G. H.
- 1980 Amino acid geochronology: Integrity of the carbonate matrix and potential of molluscan fossils. In *Biogeochemistry of Amino Acids*, edited by P. E. Hare, T. C. Hoering, and J. J. King, pp. 415-443. John Wiley and Sons, New York.
- Miller, M. R. III
- 1989 Archeological Excavations at the Gobernadora and Ojasen Sites: Doña Ana Phase Settlement in the Western Hueco Bolson, El Paso County, Texas. *Center for Archaeological Research Report 673*, New Mexico State University, Las Cruces.
- 1990 Archeological Investigations in the North Hills Subdivision, Northeast El Paso, Texas. *Batcho and Kauffman Associates Cultural Resources Report No. 100*. Las Cruces, New Mexico.
- 1993 Phase Sequences, Ceramic Chronologies, and Evolutionary Adaptive Trends: A Clarification of the Jornada Mogollon Doña Ana Phase Paper presented at the Eighth Jornada Mogollon Conference, Tularosa, New Mexico.
- Minnis, P. E.
- 1984 Peeking Under the Tortilla Curtain: Regional Interaction and Integration on the Northeastern Periphery of Casas Grandes. *American Archeology* 4(3):181-193.
- 1985 Social Adaptation to Food Stress: A Prehistoric Southwestern Example. University of Chicago Press, Chicago, Illinois.
-

1989 Prehistoric Diet in the Northern Southwest: Macroplant Remains From Four Corners Feces. *American Antiquity* 54:543-563.

1991 Botanical Remains from Mitigated Sites. In *Landscape Archeology in the Southern Tularosa Basin, Volume 2: Testing, Excavation, and Analysis*, edited by W. H. Doleman, pp. 387-394. Office of Contract Archeology, University of New Mexico. Albuquerque.

Minnis, P. E., and M. S. Toll

1991 Macrobotanical Analysis. In *Landscape Archaeology in the Southern Tularosa Basin, Volume 2: Testing, Excavation, and Analysis*, edited by W. H. Doleman, R. C. Chapman, J. A. Schutt, M. K. Swift, and K. D. Morrison. OCA/UNM Report No. 185-324E. WSMR Archaeological Report No. 91-9, pp. 387-398. Office of Contract Archaeology, University of New Mexico, Albuquerque.

Minnis, P. E., M. E. Whalen, J. H. Kelley, and J. D. Stewart

1993 Prehistoric Macaw Breeding in the North American Southwest. *American Antiquity* 58(2):270-276.

Monger, H. C.

1993a *Soil-Geomorphic and Paleoclimatic Characteristics of the Fort Bliss Maneuver Areas, Southern New Mexico and Western Texas*. Historic and Natural Resources Report 10, Cultural Resources Management Program, Directorate of the Environment, United States Army Air Defense Artillery Center, Fort Bliss, Texas.

1993b Geomorphic surfaces of maneuver and adjacent areas of Fort Bliss. In *Soil-Geomorphic and Paleoclimatic Characteristics of the Fort Bliss Maneuver Areas, Southern New Mexico and Western Texas*, edited by H. C. Monger, pp. 35-40. Historic and Natural Resources Report 10, Cultural Resources Management Program, Directorate of the Environment, United States Army Air Defense Artillery Center, Fort Bliss, Texas.

1993c Eolian alteration of soil strata on maneuver and adjacent areas of Fort Bliss. In *Soil-Geomorphic and Paleoclimatic Characteristics of the Fort Bliss Maneuver Areas, Southern New Mexico and Western Texas*, edited by H. C. Monger, pp. 11-34. Historic and Natural Resources Report 10, Cultural Resources Management Program, Directorate of the Environment, United States Army Air Defense Artillery Center, Fort Bliss, Texas.

1993d Radiocarbon and stable isotopes in the basin floor soils on Fort Bliss. In *Soil-Geomorphic and Paleoclimatic Characteristics of the Fort Bliss Maneuver Areas, Southern New Mexico and Western Texas*, edited by H. C. Monger, pp. 89-92. Historic and Natural Resources Report 10, Cultural Resources Management Program, Directorate of the Environment, United States Army Air Defense Artillery Center, Fort Bliss, Texas.

1993e Sedimentation and soil formation in maneuver and adjacent areas on Fort Bliss. In *Soil-Geomorphic and Paleoclimatic Characteristics of the Fort Bliss Maneuver Areas, Southern New Mexico and Western Texas*, edited by H. C. Monger, pp. 133-137. Historic and Natural Resources Report 10, Cultural Resources Management Program, Directorate of the Environment, United States Army Air Defense Artillery Center, Fort Bliss, Texas.

Monger, H. C., D. R. Cole, and T. H. Giordano

1993 Stable isotopes in pedogenic carbonates of fan-piedmont soils as an indicator of Quaternary climate change. In *Soil-Geomorphic and Paleoclimatic Characteristics of the Fort Bliss Maneuver Areas, Southern New Mexico and Western Texas*, edited by H. C. Monger, pp. 76-87. Historic and Natural Resources Report 10, Cultural Resources Management Program, Directorate of the Environment, United States Army Air Defense Artillery Center, Fort Bliss, Texas.

Moore, Mrs. G. E.

1947 Twelve Room House Ruin. *Bulletin of the Texas Archaeological and Palentological Society* No. 18.

Moore, Mrs. G. E., and Mrs. J. B. Wheat

1951 An Archeological Cache from the Hueco Basin, Texas. *Bulletin of the Texas Archeological and Paleontological Society* 22:144-163. Abilene, Texas.

Moore, P. B., and J. A. Webb

1978 *An Illustrated Guide to Pollen Analysis*. Hodder and Stoughton. London.

Morgan, P., W. R. Seager, and M. P. Golombek

1986 Cenozoic thermal, mechanical, and tectonic evolution of the Rio Grande Rift. *Journal of Geophysical Research* 91 (B6):6263-6276.

Morris, D. H.

1990 Changes in Groundstone Following the Introduction of Maize into the American Southwest. *Journal of Anthropological Research* 46:117-194.

Morrison, R. B.

1967 Principals of Quaternary soil stratigraphy. In *Quaternary Soils*, edited by R. B. Morrison and H. E. Wright, Jr., pp. 1-69. Proceedings Volume 9, VII Congress, International Association for Quaternary Research (INQUA). Center for Water Resources Research, Desert Research Institute, University of Nevada.

Moss, J. H.

1977 The formation of pediments: scarp backwearing or surface downwasting? In *Geomorphology of Arid Regions*, edited by D. O. Doehring, State University of New York at Binghamton, Publications. *Geography* pp. 51-78.

Motts, W. S.

1965 Hydrologic types of playas and closed valleys and some relations of hydrology to playa geology. In *Geology, Mineralogy, and Hydrology of U. S. Playas*, edited by J. T. Neal, pp. 73-104. Air Force Cambridge Research Lab, Research Report 65-116, Environmental Research Paper 96.

Motts, W. S.

1970 Some hydrologic and geologic processes influencing playa development in western United States. In *Playa Lake Symposium*, edited by C. C. Reeves, pp. 89-106.

Muehlberger, W. R., R. C. Belcher, and L. K. Goetz

1978 Quaternary faulting in Trans-Pecos Texas. *Geology* 6(6):337-340.

Mulhern, M. E.

1982 Lacustrine, fluvial, and fan sedimentation: A record of Quaternary climate change and tectonism, Pine Valley, Nevada. *Zeitschrift für Geomorphologie Supplement Band* 42:117-133.

Müller, G., and F. Wagner

1978 Holocene Carbonate Evolution in Lake Balaton (Hungary): A Response to Climate and the Impact of Man. In *Modern and Ancient Lake Sediments*, edited by A. Matter and M. E. Tucker, pp. 55-80. Blackwell, Oxford.

Nance, J.

1983 Regional sampling in archaeological survey: the statistical perspective. In *Advances in Archaeological Method and Theory* 6:289-356, edited by M. B. Schiffer. Academic Press, New York.

-
- Neck, R. W.
1987 Changing Holocene snail faunas and environments along the eastern Caprock Escarpment of Texas. *Quaternary Research* 27:312-322.
- Nelson, B.
1985 *Decoding Prehistoric Ceramics*. Southern Illinois University Press, Carbondale.
- Nelson, L. A.
1940 Paleozoic stratigraphy of Franklin Mountains, west Texas. In West Texas-New Mexico Symposium, edited by R. K. DeFord and E. R. Lloyd, *American Association of Petroleum Geologists Bulletin* 24(1):157-172.
- Nelson, L. A., and B. R. Haigh (editors)
1958 *Guide Book 1958 Field Trip, Franklin and Hueco Mountains*. West Texas Geological Society, Midland, Texas.
- Nelson, M. C.
1981 *Chipped Stone Analysis in the Reconstruction of Prehistoric Subsistence Practices: An Example from Southwestern New Mexico*. Unpublished Ph.D. dissertation, Department of Anthropology, University of California, Santa Barbara.
- Nettleton, W. D., J. E. Hawley, R. E. Nelson, and J. E. Witty
1975 Genesis of argillic horizons in soils of desert areas of the southwestern United States. *Soil Science Society of America Proceedings* 39(5):919-926.
- Newman, M. E. and P. Julig
1989 The Identification of Protein Residues on Lithic Artifacts from a Stratified Boreal Forest Site. *Canadian Journal of Archaeology* 13:119-132.
- Nilsen, T. H.
1985 Introduction. In *Modern and Ancient Alluvial Fan Deposits*, edited by T. H. Nilsen, pp. 1-20. Benchmark Papers in Geology Series, Van Nostrand Reinhold, New York, New Mexico.
- Nordt, L. C.
1992 Archaeological Geology of the Fort Hood Military Reservation, Fort Hood, Texas. *U.S. Army Fort Hood, Archaeological Resource Management Series, Research Report No. 25*.
- Nordt, L. C., T. W. Boutton, C. T. Hallmark, and M. R. Waters
1994 Late Quaternary Vegetation and Climate Changes in Central Texas Based on the Isotopic Composition of Organic Carbon. *Quaternary Research* 41(1):109-120.
- Noy-Meir, I.
1973 Desert Ecosystems: Environment and Producers. *Annual Review of Ecology and Systematics* 4:25-51.
1974 Desert Ecosystems: Higher Trophic Levels. *Annual Review of Ecology and Systematics* 5:195-214.
1981 Spatial Effects in Modeling of Arid Ecosystems. In *Arid-Land Ecosystems: Structure, Function, and Management, Volume 2*, edited by D. W. Goodall and R. A. Perry, pp. 411-432. University of Cambridge press, New York.
- O'Connel, J. F., P. K. Latz, and P. Barnett
1983 Traditional and Modern Plant Use Among the Alyawara of Central Australia. *Economic Botany* 37:80-109.
-

O'Connel, J. F., K. Hawkes, and N. B. Jones

1990 Reanalysis of Large Mammal Body Part Transport among the Hadza. *Journal of Archaeological Science* 17:301-316.

O'Hara, J., and J. Elyea

1985 Projectile Point Typology. In *Prehistoric Settlement Patterns in West-central New Mexico: The Fence Lake Coal Lease Surveys*, edited by P. Hogan, pp. 75-98. Office of Contract Archeology, University of New Mexico, Albuquerque.

O'Hara, J.

1988 Projectile Point Analysis. In *The Border Star 85 Survey: Toward an Archeology of Landscapes*, edited by T. J. Seaman, W. H. Doleman, and R. C. Chapman, pp. 191-208. UNM Project No. 185-227, Office of Contract Archeology, University of New Mexico. Albuquerque.

O'Laughlin, T. C.

1977a Excavations at the Sandy Bone Site, Doña Ana County, New Mexico. *AWANYU* 5(2):11-42.

1977b Appendix C: Excavation of Two Caves in the Mountain Zone of Fort Bliss Maneuver Area II. In *Settlement Patterns of the Eastern Hueco Bolson*, by M. Whalen. Publications in Anthropology Number 4, El Paso Centennial Museum, The University of Texas at El Paso.

1978 Appendix G: Modern Vegetation of Fort Bliss Maneuver Area I. In *Settlement Patterns of the Western Hueco Bolson*. Publications in Anthropology Number 6, El Paso Centennial Museum, The University of Texas at El Paso.

1979 *Excavations at the Transmountain Campus*. El Paso Community College El Paso, Texas. Publications in Anthropology #7, El Paso Centennial Museum, The University of Texas at El Paso, El Paso.

1980 *The Keystone Dam Site and other Archaic and Formative Sites in Northwest El Paso, Texas*. Publications in Anthropology No. 8, El Paso Centennial Museum, The University of Texas at El Paso.

1981 The Roth Site: A Pithouse Site in the Mesilla Valley of Southern New Mexico. *The Artifact* 19:133-150.

1986 Botanical Remains from Meyers Pithouse Village. Manuscript on file, Environmental Management Office, Fort Bliss.

1994 Faunal Remains from the Hueco Mountain Project. Manuscript on file, Environmental Management Office, Fort Bliss, Texas.

O'Laughlin, T. C., and T. W. Grieser

1973 *Preliminary Field Report On The Findings and Results Of The Evaluation Of The Cultural and Historical Resources of the Spillway Area of the Range Dam Lying within The Northgate National Registry Site (EPCM 31:106:3:10) in El Paso, Texas*. El Paso Centennial Museum University of Texas at El Paso.

O'Laughlin, T. C., and R. Crawford

1977 Appendix D: Modern Vegetation of the Area. In *Settlement Patterns of the Eastern Hueco Bolson*. Publications in Anthropology Number 4, El Paso Centennial Museum, The University of Texas at El Paso.

-
- O'Laughlin, T. C., V. L. Scarborough, T. B. Graves, and D. Martin
1988 Loop 375 Archaeological Project, Fort Bliss Maneuver Area I, El Paso County, Texas. An Interim Report for Phase II Testing and Phase III Recommendations for Data Recovery. Manuscript prepared for the State Department of Highways and Public Transportation, Austin.
- O'Laughlin, T. C., and D. L. Martin
1989 Loop 375 Archaeological Project, El Paso County, Texas. An Interim Report for Phase II Additional Testing and Recommendations for Phase III Data Recovery. Manuscript prepared for the State Department of Highways and Public Transportation, Austin.
- Odum, E. P.
1975 *Ecology: the Link Between the Natural and the Social Sciences*. Holt, Rinehart and Winston, second edition. New York.
- Oldfield, F., and J. Schoenwetter
1975 Discussion of the pollen analytical evidence. In *Late Pleistocene Environments of the Southern High Plains*, edited by F. Wendorf and J. Hester, pp. 149-178. Fort Burgwin Research Center Publication 9, Rancho de Taos, New Mexico.
- Opler, M. E.
1983 Mescalero Apache. In *Handbook of North American Indians, Volume 10: Southwest*. Smithsonian Institution. Washington, D. C.
- Özer, A. M., A. Weiser, H. Y. Göksu, P. Müller, D. F. Regulla, and O. Erol
1989 ESR and TL age determination of caliche nodules. *Applied Radiation and Isotopes* 40:1159-1162.
- Padzur, A., M. F. Padzur, L. Starkel, and J. Szulc
1988 Stable Isotopes of Holocene Calcareous Tufa in Southern Poland as Paleoclimatic Indicators. *Quaternary Research* 30:177-189.
- Parkes, P. A.
1986 *Current Scientific Techniques in Archaeology*. St. Martin's Press, New York.
- Parkington, J.
1987 On Stable Isotopes and Dietary Reconstruction. *Current Anthropology* 28:91-93.
- Parson, A. J.
1988 *Hillslope Form*. Routledge, London.
- Paterson, W. S. B., R. M. Koerner, D. Fisher, S. J. Johnsen, H. B. Clausen, W. Dansgaard, P. Bucher, and H. Oeschger
1977 An Oxygen Isotope Climatic Record from the Devon Island Ice Cap, Arctic Canada. *Nature* 266:508-511.
- Patton, P. C., and S. A. Schumm
1975 Gully erosion northwestern Colorado--A threshold phenomenon. *Geology* 3:88-90.
- 1981 Ephemeral stream processes: Implications for studies of Quaternary valley fills. *Quaternary Research* 15:24-43.
-

-
- Pearsall, D. M.
1978 Phytolith Analysis of Archaeological Soils: Evidence for Maize Cultivation in Formative Ecuador. *Science* 199: 177-178.
- Pearsall, D.M.
1983 Evaluating the Stability of Subsistence Strategies by Use of Paleoethnobotanical Data. *Journal of Ethnobiology* 2:121-137.
- Pena, S. D. J., R. Chakraborty, J. T. Epplen, and A. J. Jeffreys
1993 *DNA Fingerprinting: State of the Science*. Birkhauser, Switzerland.
- Pennington, C. W.
1962 *The Tarahumar of Mexico Their Environment and Material Culture*. University of Utah Press. Salt Lake City.

1983 Tarahumara. In *Handbook of North American Indians, Volume 10, Southwest*, pp. 276-289. Smithsonian Institution, Washington, D.C.
- Perrin, R. M. S., F. H. Willis, and C. A. H. Hodge
1964 Dating of humus podzols by residual radiocarbon dating. *Nature* 203:165-166.
- Perry, R. J.
1991 *Western Apache Heritage People of the Mountain Corridor*. The University of Texas Press. Austin.
- Peterson, F. F.
1981 Landforms of the Basin and Range Province, Defined for Soil Survey. *Nevada Agricultural Experiment Station, Technical Bulletin* 28.
- Phelps, A.
1967 Six Stone Balls - A Cache. *The Artifact* 5(1):21-29. El Paso Archeological Society Press. El Paso.
- Pigott, J. D.
1977 Reconnaissance Geology: Implications for the analysis of human occupation. In *A Cultural Resource Inventory and Assessment of McGregor Guided Missile Range, Otero County, New Mexico, Part III: Botanical and Geological Studies*. University of Texas at Austin, Texas Archeological Survey, Research Report 65, Part III, pp. 94-158.
- Piperno, D. R.
1988 *Phytolith Analysis: An Archaeological and Geological Perspective*. Academic Press, New York.
- Plog, F.
1974 *The Study of Prehistoric Change*. Academic Press, New York.
- Plog, F., R. Effland, and D. F. Green
1978 Inferences Using the SARG data bank. In *Investigations of the Southwest Anthropological Research Group*, edited by R. C. Euler and G. J. Gumerman, pp. 139-148. Museum of Northern Arizona, Flagstaff.
- Polach, H. A., and A. B. Costin
1971 Validity of soil organic matter radiocarbon dating: buried soils in Snowy Mountains, southeastern Australia as example. In *Paleopedology: Origin, Nature, and Dating of Paleosols*, D. Yaalon, editor. Israel University Press, New York.
-

Polanyi, K.

- 1975 Traders and Trade. In *Ancient Civilization and Trade*, edited by J. A. Sabloff and C. C. Lamberg-Karlovsky. University of New Mexico Press, Albuquerque.

Ponti, D. J.

- 1985 The Quaternary Alluvial Sequence of the Antelope Valley, California. *Geological Society of America Special Paper* 203:79-96.

Pool, M. D.

- 1985 *The Western Apache Settlement System and Its Implications for the Prehistoric Early Mogollon Period*. Unpublished M.A. thesis, The University of Texas at Austin.

Popp, C. J., J. W. Hawley, D. W. Love, and M. Diehn

- 1988 Use of radiometric (Cs-137, Pb-210), geomorphic, and stratigraphic techniques to date recent oxbow sediments in the Rio Puerco drainage Grants uranium region, New Mexico. *Environmental Geology and Water Science* 11(3):253-269.

Poppler, V. S., and C. A. Hastorf

- 1988 Introduction. In *Current Paleoethnobotany: Analytical Methods and Cultural Interpretations of Archaeological Plant Remains*, edited by C. A. Hastorf and V. S. Popper, pp. 1-16. The University of Chicago Press, Chicago, Illinois.

Pray, L. C.,

- 1961 Geology of the Sacramento Mountains Escarpment, Otero County, New Mexico. *State Bureau of Mines and Mineral Resources Bulletin* 35. New Mexico Institute of Mining and Technology, Socorro.

Price, J. G., and C. D. Henry

- 1985 Summary of Tertiary stress orientations and tectonic history in Trans-Pecos Texas. In *Structure and Tectonics of Trans-Pecos Texas*, edited by P. W. Dickerson and W. R. Muehlberger. West Texas Geological Society Field Conference Publication 85-81, pp. 149-151.

Purdy, B. A., and D. E. Clark

- 1987 Weathering of inorganic materials: Dating and other applications. In *Advances in Archaeological Method and Theory* 11:211-253, edited by M. B. Schiffer. Academic Press, New York.

Pye, K.

- 1983 Early post-depositional modification of aeolian dune sands. In *Developments in Sedimentology* 38: *Eolian Sediments and Processes*, edited by M. E. Brookfield and T. S. Ahlbrandt, pp. 197-221. Elsevier, Amsterdam.

Quimby, B., and V. R. Brook

- 1967 A Folsom Site Near El Paso, Texas. *The Artifact* 5(4):31-47.

Reeves, C. C., Jr.

- 1965 Pluvial Lake Palomas, Northwestern Chihuahua, Mexico, and Pleistocene Geologic History of South-Central New Mexico. In *Guidebook of Southwestern New Mexico II*, edited by J. P. Fitzsimmons and C. Lochman-Balk. New Mexico Geological Society, Guidebook 16th Field Conference, pp. 199-203.

- 1969 *Pluvial Lake Palomas, Northwestern Chihuahua, Mexico*. New Mexico Geological Society, Guidebook 20th Field Conference, pp. 143-154.
-

Reineck, H. E., and I. B. Singh

1980 *Depositional Sedimentary Environments: With Reference to Terrigenous Clastics (2nd Edition)*. Springer-Verlag, New York.

Renfrew, C.

1979 *Before Civilization, The Radiocarbon Revolution and Prehistoric Europe*. Cambridge University Press, Cambridge.

Renfrew, C., and P. Bahn

1991 *Archaeology: Theories, Methods and Practice*. Thames and Hudson Ltd. London.

Rhode, D.

1988 Measurements of Archaeological Diversity and the Sample Size Effect. *American Antiquity* 53:708-716.

Rightmire, C. T.

1967 *A radiocarbon study of the age and origin of caliche deposits*. Unpublished M.A. thesis, the University of Texas at Austin.

Ritter, D. C.

1986 *Process Geomorphology*. Wm. C. Brown, Dubuque, Iowa.

Rovner, I.

1971 Potential of opal phytoliths for use in paleoecological reconstruction. *Quaternary Research* 1:343-359.

1983 Plant Opal Phytolith Analysis: Major Advances in Archaeobotanical Research. In *Advances in Archaeological Method and Theory* 6:225-266, edited by M. B. Schiffer. Academic Press, New York.

Rugge, D.

1986 Petrographic Analysis of Mimbres Series Ceramics from the Fort Bliss Military Reservation, Texas and New Mexico. Manuscript on file, Directorate of Environment, Fort Bliss, Texas.

1988 Petrographic Studies. In *The Border Star Survey: Toward an Archeology of Landscapes*, edited by T. J. Seaman, W. H. Doleman, and R. C. Chapman, pp. 185-189. Office of Contract Archaeology, University of New Mexico, Albuquerque.

Ruhe, R. V.

1964 Landscape morphology and alluvial deposits in southern New Mexico. *Annals of the Association of American Geographers* 54:147-159.

1967 Geomorphic Surfaces and Surficial Deposits in Southern New Mexico. *Memoir 18, New Mexico Bureau of Mines and Mineral Resources*.

Runyan, J. W., and J. A. Hedrick

1973 Pottery Types of the SWFAS Area. In *Transactions of the Eighth Regional Archeological Symposium for Southeastern New Mexico and Western Texas*, pp. 19-45. Lea County Archeological Society, Hobbs, New Mexico.

Russel, B., and R. J. Hard

1983 Faunal Analysis of the Conejo Site (FB 46) and 3:739 from a Seasonality Perspective. Manuscript on file, Environmental Management Office, Fort Bliss, Texas, pp. 245.

Russell, P.

1968 Folsom Complex Near Orogrande, New Mexico (Sites EPAS-21, EPAS-22). *The Artifact* 6(2):11-16.

Rust, B. R.

1979 Facies models 2: Coarse alluvial deposits. In *Facies Models*, edited by R. G. Walker, pp. 9-21. Geoscience Canada, Reprint Series 1.

Rutter, N. W. (editor)

1985 Dating Methods of the Pleistocene and their Problems, reprinted with revisions from a series of papers in *Geoscience Canada* 1978-198: Reprint Series 2.

Satterwhite, M. B., and J. Ehlen

1980 Vegetation and Terrain Relationships in South-Central New Mexico and Western Texas. U.S. Army Engineer Topographic Laboratories, Fort Belvoir, Virginia.

1982 Landform-Vegetation Relationships in the Northern Chihuahuan Desert. In *Aridic Soils and Geomorphic Processes*, edited by D. H. Yaalon. CATENA Supplement 1, West Germany.

Sayles, E. B.

1935 An Archaeological Survey of Texas. *Medallion Papers, No. 17*. Gila Pueblo, Globe, Arizona.

Sayles, E. B., and E. Antevs

1941 The Cochise Culture. *Medallion Papers 29*. Gila Pueblo, Globe, Arizona.

Scarborough, V. L.

1986 Meyer Pithouse Village. Manuscript on file, Historic and Natural Resources Report Series, Archaeology Branch, Directorate of Environment, U.S. Army Air Defense Artillery Center, Fort Bliss.

1992 Ceramics, Sedentism, and Agricultural Dependency at a Late Pithouse/Early Pueblo Period Village. *Research in Economic Anthropology, Supplement 6*, pp. 307-333.

Schaafsma, P., and C. F. Schaafsma

1974 Evidence for the Origins of the Pueblo Katchina Cult as Suggested by Southwestern Rock Art. *American Antiquity* 39(4):535-545.

Schaffer, B. S.

1992 Quarter-Inch Screening: Understanding Biases in Recovery of Vertebrate Faunal Remains. *American Antiquity* 57:129-136.

Scharpenseel, H. W.

1971 Radiocarbon dating of soils - problems, troubles, hopes. In *Paleopedology: Origin, Nature, and Dating of Paleosols*, D. Yaalon, editor. Israel University Press, New York.

1979 Soil fraction dating. In *Proceedings of the 9th International Radiocarbon Conference*, edited by R. Berger and H. E. Suess, pp. 277-283.

Schiffer, M. B.

1983 Towards the identification of formation processes. *American Antiquity* 48:675-706.

1987 *Formation Processes of the Archaeological Record*. University of New Mexico Press.

Schiffer, M. B., and S. J. Wells

1982 Archaeological Surveys: Past and Future. In *Hohokam and Payatan*, edited by R. H. McGuire and M. B. Schiffer, pp. 345-383. Academic Press, New York.

Schlanger, S. H.

1991 On Manos, Metates, and the History of Site Occupation. *American Antiquity* 56:460-473.

Schmidt, K. H.

1994 Hillslopes as evidence of climatic change. In *Geomorphology of Desert Environments*, edited by Abrahms, A. D., and A. J. Parsons, pp. 553-570. Chapman and Hall, London.

Schnitzer, M., and S. U. Khan

1972 *Humic Substances in the Environment*. Marcel Dekker, New York.

Schoeninger, M. J., and M. J. DeNiro,

1984 Nitrogen and Carbon Isotopic Composition of Bone Collagen from Marine and Terrestrial Animals. *Geochimica Cosmochimica Acta* 48:625-639.

Schroeder, A. H.

1974 *A Study of Apache Indians, Part 1*. Garland Publishing, Inc. New York.

Schumm, S. A.

1973 Geomorphic thresholds and complex response of drainage systems. In *Fluvial Geomorphology*, edited by M. Morisawa, pp. 299-310. Binghamton, New York. Publications in Geomorphology, State University of New York.

1977 *The Fluvial System*. John Wiley and Sons, New York.

Schutt, J. A.

1992 Geomorphic and Behavioral Processes Affecting Site and Assemblage Formation: The Testing Data. In *Landscape Archaeology in the Southern Tularosa Basin*. Volume 3. Archaeological Distributions and Prehistoric Human Ecology, edited by W. H. Doleman, R. C. Chapman, R. L. Stauber, and J. Piper, pp. 53-71. Office of Contract Archaeology, Albuquerque, New Mexico.

Schwarcz, H. P., and B. Blackwell

1985 Dating Methods of the Pleistocene and Their Problems: II. Uranium Series Disequilibrium Dating. In *Dating Methods of the Pleistocene and Their Problems*. Reprinted with revisions from a series of papers in *Geoscience Canada 1978-1982*, edited by N. W. Rutter, pp. 9-17. *Geoscience Canada, Reprint Series 2*.

Schweingruber, F. H., O. U. Bräker, and E. Schär

1979 Dendroclimatic studies on conifers from central Europe and Great Britain. *Boreas* 8:427-452.

Scott, C. J.

1983 The Evolution of Mimbres Pottery. In *Mimbres Pottery: Ancient Art of the American Southwest*, by J. J. Brody, pp. 39-68. Hudson Hills Press, New York.

Scott, C. L.

1993 Phytolith analysis of three locations on the Fort Bliss Military Reservation, New Mexico: A feasibility study. In *Soil-Geomorphic and Paleoclimatic Characteristics of the Fort Bliss Maneuver Areas, Southern New Mexico and Western Texas*, edited by H. C. Monger, pp. 129-131. Historic and Natural Resources Report 10,

Cultural Resources Management Program, Directorate of the Environment, United States Army Air Defense Artillery Center, Fort Bliss, Texas.

Seager, W. R.

1975 Cenozoic tectonic evolution of the Las Cruces area, New Mexico. In *Guidebook of the Las Cruces Country*, edited by W. R. Seager, R. E. Clemons, and J. F. Callendar. New Mexico Geological Society, Guidebook 26th Field Conference, pp. 241-250.

1980 Quaternary fault system in the Tularosa and Hueco Basins, southern New Mexico and West Texas. In *Trans-Pecos Region, New Mexico and West Texas*, edited by P. W. Dickerson, J. M. Hoffer, and J. F. Callendar. New Mexico Geological Society Annual Field Conference Guidebook No. 31, pp. 131-135.

1981 Geology of Organ Mountains and Southern San Andres Mountains, New Mexico. New Mexico Bureau of Mines and Mineral Resources. *Memoir* 36, pp. 97.

Seager, W. R., and Brown, L. F.

1978 The Organ Caldera. *New Mexico Geological Society, Special Publication* 7, pp. 139-149.

Seager, W. R., and P. Morgan

1979 Rio Grande rift in southern New Mexico, west Texas, and northern Chihuahua. In *Rio Grande Rift, Tectonics and Magnetism*, edited by R. E. Riecker, pp. 87-106. American Geophysical Union, Washington, D.C.

Seager, W. R., J. W. Hawley, F. E. Kottowski, and S. A. Kelley

1987 Geology of east half of Las Cruces and Northeast El Paso 1° x 2° sheets, New Mexico. *New Mexico Bureau of Mines and Mineral Resources, Geologic Map* 57.

Seager, W. R., M. Shafiqullah, J. W. Hawley, and R. F. Marvin

1984 New K-Ar dates from basalts and the evolution of the southern Rio Grande. *Geological Society of America Bulletin* 95:87-99.

Sealy, J. C., N. J. van der Merwe, J. A. L. Thorpe, and J. L. Lanham

1987 *Nitrogen isotopic ecology in southern Africa: Implications for evolutionary and dietary tracing.*

Seaman, T. J., and B. Mills

1988 El Paso Brownware Rim Analysis. In *The Border Star 85 Survey: Towards an Archaeology of Landscapes*, edited by T. J. Seaman, W. H. Doleman, and R. Chapman, pp. 169-185. Office of Contract Archaeology, Albuquerque, New Mexico.

Seaman, T. J., W. H. Doleman, and R. C. Chapman

1988 *The Border Star 85 Survey Toward An Archeology of Landscapes.* UNM Project No. 185-227, Office of Contract Archeology, University of New Mexico, Albuquerque.

Selby, M. J.

1982 *Hillslope Materials and Processes.* Oxford University Press.

Semken, H. A., Jr.

1961 Fossil vertebrates from Longhorn Cavern, Burnet County, Texas. *Texas Journal of Science* 13:290-310.

Shackleton, N. J.

1967 Oxygen isotope analyses and Pleistocene temperatures re-assessed. *Nature* 215:15-17.

-
- Shackleton, N. J., and N. D. Opdyke
1973 Oxygen isotope and paleomagnetic stratigraphy of equatorial Pacific core V28-238: oxygen isotope temperatures and ice volumes on a 105 year and 106 year scale. *Quaternary Research* 3:39-55.
- Shafer, H. A., and A. J. Taylor
1986 Mimbres Mogollon Architectural Development and Ceramic Style Change. *Journal of Field Archeology* 13:43-68.
- Sharp, R. P.
1963 Wind ripples. *Journal of Geology* 71:617-636.
- Shea, J. J.
1992 Lithic Microwear Analysis in Archaeology. *Evolutionary Anthropology* 1:143-150.
- Shelley, P. H., and F. L. Nials
1983 A preliminary evaluation of aeolian processes in artifact dislocation and modification: An experimental approach to one depositional environment. *Proceedings of the New Mexico Archaeological Council* 5:50-56.
- Shelly, P. H., J. L. Montgomery, and K. Bowman
1988 Obsidian Sourcing and Hydration Studies. In *The Border Star 85 Survey: Toward an Archeology of Landscapes*, edited by T. J. Seaman, W. H. Doleman and R. C. Chapman. UNM Project No. 185-227, Office of Contract Archeology, University of New Mexico, Albuquerque.
- Shennan, S.
1988 *Quantifying Archaeology*. Academic Press, New York.
- Shepard, A. O.
1956 *Ceramics for the Archaeologist*. Carnegie Institution. Washington, D.C.
- Shreve, F.
1942 The desert vegetation of North America. *Botanical Review* 8:195-246.
- Sigleo, A. C.
1975 Turquoise Mine and Artifact Correlation for Snaketown Site, Arizona. *Science* No. 4201:459-460.
- Silberbauer, G. B.
1972 The G/wi Bushmen. In *Hunters and Gatherers Today: A Socioeconomic Study of Eleven Such Cultures in the Twentieth Century*, edited by M. G. Bicchieri, pp. 271-326. Holt, Rinehart and Winston, New York.
1981 *Hunter and Habitat in the Central Kalahari Desert*. Cambridge University Press, New York.
- Sillen, A., J. C. Sealy, and N. J. Van Der Merwe
1989 Chemistry and Paleodietary Research: No More Easy Answers. *American Antiquity* 54:504-512.
- Simmons, A. H., A. L. Wiener-Stodder, D. D. Dykeman, and P. A. Hicks
1989 Human Adaptations and Cultural Change in the Greater Southwest: An Overview of Archeological Resources in the Basin and Range Province. *Arkansas Archeological Survey Research Series No. 32*. Final Report submitted to the US Army Corps of Engineers, Southwestern Division.
-

Simms, S. R.

- 1984 Experiments on Artifact Movement in Sand Dunes. In *Archaeological Investigations in the Sevier and Escalante deserts, Western Utah*, edited by S. R. Simms and M. C. Isgreen. University of Utah Archaeological Center, Reports of Investigations pp. 83-12.

Singer, M. J., and P. Janitzky

- 1986 Field and Laboratory Procedures Used in a Soil Chronosequence Study. *Bulletin 1648, United States Geological Survey*. Washington, D. C.

Skelton, D. W., M. D. Freeman, N. K. Smiley, J. D. Pigott, and D. S. Dibble

- 1981 A Cultural Resources Inventory and Assessment of Doña Ana Range, New Mexico. *Texas Archaeological Survey, Research Report No. 69*, The University of Texas at Austin.

Skinner, A. R., and C. E. Shawl

- 1994 ESR dating of terrestrial Quaternary shells. *Quaternary Geochronology (Quaternary Science Reviews)* 13:679-684.

Smiley, N. K.

- 1977 Analysis of Ceramic Materials From McGregor Range. In A Cultural Resource Inventory and Assessment of McGregor Guided Missile Range, Part II: Special Archaeological Studies. *Texas Archaeological Survey Research Report 65*, pp. 129-261. The University of Texas at Austin.

- 1979 Evidence for Ceramic Trade Specialization in the Southern Jornada Branch. In *Jornada Mogollon Archaeology: Proceedings of the First Jornada Conference*, edited by P. H. Beckett and R. N. Wiseman. New Mexico State University, Las Cruces.

Smith, B. N.

- 1971 Carbon Isotope Ratios of Respired CO₂ from Castor Bean, Corn, Peanut, Pea, Radish, Squash, Sunflower, and Wheat Seedlings. *Plant and Cell Physiology* 12:451-455.

- 1972 Natural Abundance of the Stable Isotopes of Carbon in Biological Systems. *Bioscience* 22:226-231.

Smith, B. N., and S. Epstein

- 1971 Two Categories of C13/C12 Ratios for Higher Plants. *Plant Physiology* 47:380-384.

Smith, B. N. and W. V. Brown

- 1973 The Kranz Syndrome in the Gramineae as Indicated by Carbon Isotopic Ratios. *American Journal of Botany* 60:505-513.

Smith, B. R., E. J. Rhodes, N. A. Spooner, and M. J. Aitken

- 1990 Optical dating of sediments: Initial quartz results from Oxford. *Archaeometry* 32(1):19-31.

Smith, P. R., and M. T. Wilson

- 1990 Detection of Haemoglobin in Human Skeletal Remains by ELISA. *Journal of Archaeological Science* 17:255-268.

Soil Survey Staff

- 1951 *Soil Survey Manual*. United States Department of Agriculture Handbook, 18. U.S. Government Printing Office, Washington, D.C.
-

1975 *Soil Taxonomy: A Basic System for Making and Interpreting Soil Surveys*. United States Department of Agriculture Handbook, 436. U.S. Government Printing Office, Washington, D.C.

1990 *Keys to Soil Taxonomy (Fourth Printing)*. SMSS Technical Monograph 19. Soil Management Support Services, Virginia Polytechnic Institute and State University, Blacksburg, Virginia.

Southward, J. A.

1979 A Summary of Ceramic Technology, Plant Remains, and Shell Identification Analyses from LA 4921, Three Rivers, New Mexico. In *Jornada Mogollon Archaeology: Proceedings of the First Jornada Conference*, edited by P. H. Beckett and R. N. Wiseman, New Mexico State University, Las Cruces.

Speth, J. D.

1986 Foreword - 1986. In *Jumano and Patarabueye Relations at La Junta de Los Rios*. Anthropological Papers Museum of Anthropology, University of Michigan No. 77. Ann Arbor, Michigan.

Spier, L.

1933 *Yuman Tribes of The Gila River*. The University of Chicago Press. Chicago, Illinois.

Stallings, W. S.

1931 El Paso Polychrome. *Laboratory of Anthropology, Technical Series, No. 3*. Museum of New Mexico, Santa Fe.

1932 Notes on the Pueblo Culture in South-Central New Mexico and in the Vicinity of El Paso, Texas. *American Anthropologist* 34:67-78.

Stevens, J. B., and M. S. Stevens

1985 Basin and Range deformation and depositional timing, Trans-Pecos Texas. In *Structure and Tectonics of Trans-Pecos Texas*, edited by P. W. Dickerson and W. R. Muehlberger. West Texas Geological Society Field Conference Publication 85-81, pp. 157-163.

Steward, J. H.

1938 Basin-Plateau Aboriginal Sociopolitical Groups. *Bureau of American Anthropology, Bulletin 120*, Washington, D.C.

Stokes, S.

1992 Optical dating of young (modern) sediments using quartz: results from a selection of depositional environments. *Quaternary Science Reviews* 11:153-159.

Stone, R. O.

1956 *A Geologic Investigation of Playa Lakes*. Unpublished Ph.D. dissertation, The University of Southern California.

Stone, T. T.

1994 The Impact of Raw-Material Scarcity on Ground-Stone Manufacture and Use: An Example from the Phoenix Basin Hohokam. *American Antiquity* 59:680-694.

Stowe, L. G., and J. A. Teeri

1978 The Geographic Distribution of C4 Species of the Dicotyledonae in Relation to Climate. *The American Naturalist* 112:609-623.

Strain, W. S.

1966 Blanco Mammalian Fauna and Pleistocene Formations, Hudspeth County, Texas: The University of Texas (Austin), *Texas Memorial Museum, Bulletin 10*.

1969a Late Cenozoic Strata of the El Paso area. In *Border Stratigraphy Symposium*. New Mexico Bureau of Mines and Mineral Resources, Circular 104, pp. 122-123.

1969b Late Cenozoic Strata of the El Paso-Juarez area. In *Guidebook of the Border Region*, edited by D. A. Córdoba, S. A. Wengerd, and J. Shomaker. New Mexico Geological Society, 20th Field Conference, pp. 155-157.

1971 Late Cenozoic Bolson integration in the Chihuahua tectonic belt. In *The Geologic Framework of the Chihuahua Tectonic Belt: Symposium in Honor of Professor Ronald K. DeFord*, edited by K. Seewald, and D. Sundeen, West Texas Geological Society, Publication. 71-59, pp. 167-173.

1980 Pleistocene Rocks in El Paso and Hudspeth Counties, Texas. In *Trans-Pecos Region, Southeastern New Mexico and West Texas*, edited by P. W. Dickerson and J. Hoffer. New Mexico Geological Society, Guidebook 31st Field Conference, pp. 179-181.

Stratton, S.

1994 Faunal Remains, Small Site Archaeological Project 90-11, Fort Bliss, Texas. In *Small Sites in the Central Hueco Bolson; A Final Report on Project 90-11*, by R. P. Mauldin, T. B. Graves, and M. Bentley. Historic and Natural Resources Report Series, Archaeology Branch, Directorate of Environment, U.S. Army Air Defense Artillery Center, Fort Bliss.

Struever, S.

1968 Woodland Subsistence-Settlement Systems in the Lower Illinois Valley. In *New Perspectives in Archeology*, edited by S. R. and L. R. Binford, pp. 288-312. Aldine, Chicago, Illinois.

1968 Flotation Techniques for the Recovery of Small Scale Archaeological Remains. *American Antiquity*. 33:353-362.

Stuart, D. E., and R. P. Gauthier

1984 *Prehistoric New Mexico: Background for Survey*. Historic Preservation Office, Santa Fe.

Stubbs, S. A.

1930 Preliminary Report of Excavations Near la Luz and Alamogordo, New Mexico. *El Palacio* XXIX, No. 1:3-9. Santa Fe, New Mexico.

Stuiver, M., and P. J. Reimer

1993 Extended 14C Database and Revised CALIB Radiocarbon Calibration Program. *Radiocarbon* 35:215-230.

Styles, B. W.

1981 Faunal Exploitation and Resource Selection: Early Late Woodland Subsistence in the Lower Illinois Valley. *Northwestern University Archaeology Program Scientific Papers No. 3*. Northwestern University.

Suhm, D. A., and E. B. Jelks

1962 Handbook of Texas Archeology: Type Descriptions. *Texas Archeological Society, Special Publications 1, Texas Memorial Museum Bulletin 4*. Austin, Texas.

Summerfield, M. A.

1991 *Global Geomorphology*. Longman Scientific and Technical, London.

Sutton, S. R., and D. W. Zimmerman

1976 Thermoluminescent dating using zircon grains from archaeological ceramics. *Archaeology* 18:125-134.

Swift, M. K., and W. H. Doleman

1991 Factors Complicating Interpretation. In *Landscape Archaeology in the Southern Tularosa Basin, Volume 2: Testing, Excavation, and Analysis*, edited by W. H. Doleman, R. C. Chapman, J. A. Schutt, M. K. Swift, and K. D. Morrison, pp. 418-421. Office of Contract Archaeology, University of New Mexico, Albuquerque.

Szabo, B. J.

1990 Ages of Travertine Deposits in Eastern Grand Canyon National Park, Arizona. *Quaternary Research* 34:24-32.

Szarek, S. R., and I. P. Ting

1977 The Occurrence of Crassulacean Acid Metabolism Among Plants. *Photosynthetica* 11:330-342.

Tagg, M.

1993 Early Cultigens from Fresnal Shelter, Southeastern New Mexico. Paper presented at the 8th Jornada Mogollon Conference, Tularosa, New Mexico.

Tan, K. H.

1982 *Principals of Soil Chemistry*. Marcel Dekker, New York.

Tanaka, J.

1976 Subsistence Ecology of Central Kalahari San. In *Kalahari Hunter-Gatherers Studies of the !Kung San and Their Neighbors*, edited by R. B. Lee and I. DeVore. Harvard University Press, Cambridge, Massachusetts.

1980 *The San Hunter-Gatherers of the Kalahari A Study in Ecological Anthropology*. Translated by D. W. Hughes. University of Tokyo Press. Tokyo.

Taylor, W. W.

1964 Tethered Nomadism and Water Territoriality: An Hypothesis. *Acts of the 35th International Congress of Americanists*, pp. 197-203.

Tchakerian, V. P.

1994 Paleoclimatic implications from desert dunes and sediments. In *Geomorphology of Desert Environments*, edited by Abrahms, A. D., and A. J. Parsons, pp. 631-643. Chapman and Hall, London.

Teeri, J. A.

1988 Interaction of Temperature and Other Environmental Variables Influencing Plant Distribution. In *Plants and Temperature*, S. P. Long and F. I. Woodward, editors, pp. 77-89. Symposia for the Society for Experimental Biology, No. 42. Company of Biologists, Ltd., Cambridge, England.

Teeri, J. A. and L. G. Stowe

1976 Climatic Patterns and the Distribution of C4 Grasses in North America. *Oecologia* 23:1-12.

Thomann, W. F., and J. M. Hoffer

1985 Petrology and geochemistry of the Precambrian Mundy Breccia, Franklin Mountains, Texas. *Texas Journal of Science* 36:267-281.

Thomann, W. F., and R. L. Hoffer

1989 Stratigraphy, sedimentary structures and petrology of the Middle Proterozoic Castner Marble, Franklin Mountains, Far West Texas. *University of Wyoming, Contributions to Geology* 27:33-39.

Thompson, M., and P. H. Beckett

1979 A Study of Prehistoric Campsites in Northeast El Paso. *Cultural Resources Management Division, Department of Sociology and Anthropology NMSU Report No. 310.*

Thompson, P., H. P. Schwarcz, and D. C. Ford

1976 Stable Isotope Geochemistry, Geothermometry, and Geochronology of Speleothems from West Virginia. *Geological Society of America Bulletin* 87:1730-1738.

Thompson, R. S., C. Whitlock, P. J. Bartlein, S. P. Harrison, and W. G. Spaulding

1993 Climatic changes in the western United States since 18,000 BP. In *Global Climates Since the Last Glacial Maximum*, edited by H. E. Wright, Jr., J. E. Kutzbach, T. Webb III, W. F. Ruddiman, F. A. Street-Perrott, and P. J. Bartlein, pp. 468-513. University of Minnesota Press, Minneapolis.

Thornbury, W. D.

1965 *Regional Geomorphology of the United States*. John Wiley and Sons, New York.

Tight, W. G.

1905 Bolson plains of the Southwest. *American Geologist* 36:271-284.

Timmons, W. H.

1990 *El Paso: A Borderlands History*. Texas Western Press, El Paso.

Tindale, N. B.

1972 The Pitjandjara. In *Hunters and Gatherers Today: A Socioeconomic Study of Eleven Such Cultures in the Twentieth Century*, edited by M. G. Bicchieri, pp. 217-268. Holt, Rinehart, and Winston, New York.

Toomey, D. F., and J. A. Babcock

1983 Precambrian and Paleozoic Algal Carbonates, West Texas and Southern New Mexico. *Colorado School of Mines, Professional Contribution* 11.

Toomey, R. S., III

1993 *Late Pleistocene and Holocene Faunal and Environmental Changes at Hall's Cave, Kerr County, Texas*. Unpublished Ph.D. dissertation, University of Texas at Austin.

Trierweiler, W. N.

1994 Managing Cultural Resources on Large Military Installations. In *Significance Standards for Prehistoric Cultural Resources: A Case Study from Fort Hood, Texas*, by G. L. Ellis, C. Lintz, W. N. Trierweiler, and J. M. Jackson, pp. 1-12. USACERL Technical Report CRC-94/04. United States Army Corps of Engineers, Construction Engineering Research Laboratories. Urbana, Illinois.

Tringham, R., G. Cooper, G. Odell, B. Voytek, and A. Whitman

1974 Experimentation in the Formation of Edge Damage: A New Approach to Lithic Analysis. *Journal of Field Archaeology* 1:171-196.

Tseo, G.

1990 Reconnaissance of the dynamic characteristics of an active Strzelecki Desert longitudinal dune, southcentral Australia. *Zeitschrift für Geomorphologie* 34:19-35.

Turner, E. S., and T. R. Hester

1985 *A Field Guide to Stone Artifacts of Texas Indians*. Texas Monthly Press. Austin.

Twidale, C. R.

1981 Origins and environments of pediments. *Journal of the Geological Society of Australia* 28:423-434.

Twiss, P. C.

1987 Grass-opal phytoliths as climatic indicators of the Great Plains Pleistocene. In *Quaternary Environments of Kansas*, edited by W. C. Johnson, pp. 179-188. Kansas Geological Survey Guidebook Series 5.

Ungar, J. E., and P. K. Haff

1987 Steady-state saltation in air. *Sedimentology* 34:289-299.

United States Army Corps of Engineers

1993 *Range Master Plan, Fort Bliss, Texas*. U.S. Army Corps of Engineers, Fort Worth District.

Upham, S.

1984 Adaptive Diversity and Southwestern Abandonment. *Journal of Anthropological Research* 40 2:235-256.

1988 Archaeological Visibility and the Underclass of Southwestern Prehistory. *American Antiquity* 53:245-261.

1992 Interaction and Isolation - The Empty Spaces in Panregional Political and Economic Systems. In *Resources, Power, and Interregional Interaction*, edited by E. M. Schortman and P. A. Urban. Plenum Press, New York.

1994 Ten years After: Adaptive Diversity and Southwestern Archaeology. *Journal of Anthropological Research* 50:155-157.

Upham, S., and R. S. MacNeish

1993 The Evolution of Maize in the Jornada Region of New Mexico and its Implications for the Southwest. In *Preliminary Investigations of the Archaic in the Region of Las Cruces, New Mexico*, edited by R. S. MacNeish. Historic and Natural Resources Report No. 9, Cultural Resources Management Program, Directorate of Environment, United States Army Air Defense Artillery Center, Fort Bliss, Texas.

Upham, S., C. M. Stevenson, R. E. Newton, and M. Johnson

1986 Chronometric Dating of San Pedro Style Projectile Points in Southern New Mexico. In *Mogollon Variability*, edited by C. Benson and S. Upham, pp. 88-96. Occasional Papers of the University Museum 15, pp. 88-96. New Mexico State University, Las Cruces.

Upham, S., R. S. MacNeish, W. C. Galinat, and C. M. Stevenson

1987 Evidence Concerning the Origin of Maiz de Ocho. *American Anthropologist* 89, No. 2:410-419.

Urey, H. C.

1947 The Thermodynamic Properties of Isotopic Substances. *Journal of Chemical Society* 152:190-219.

Valladas, H.

1978 Thermoluminescence dating of burnt stones from a prehistoric site. *PACT* 2:180-183.

van der Merwe, M. J.

1982 Carbon Isotopes, Photosynthesis, and Archaeology. *American Scientist* 70:596-606.

-
- Van Devender, T. R.
1990 Late Quaternary Vegetation and Climate of the Chihuahuan Desert, United States and Mexico. In *Packrat Middens: the last 40,000 Years of Biotic Change*, pp. 104-133. The University of Arizona Press, Tucson.
- Van Devender, T. R., and D. H. Riskind
1979 Late Pleistocene and Early Holocene Plant Remains from Hueco Tanks State Historical Park: The Development of a Refugium. In *The Southwestern Naturalist* 24(1):127-140.
- Van Devender, T. R., and W. G. Spaulding
1979 Development of Vegetation and Climate in the Southwestern United States. In *Science* 24, No. 4394:701-710.
- Van Devender, T. R., J. L. Betancourt, and M. Wimberly
1984 Biogeographic implications of a packrat midden sequence from the Sacramento Mountains, south-central New Mexico. *Quaternary Research* 22:344-360.
- Vanderhill, J. B.
1986 *Lithostratigraphy, Vertebrate Paleontology, and Magnetostratigraphy of the Plio-Pleistocene Sediments in the Mesilla Basin, New Mexico*. Unpublished Ph.D. dissertation, The University of Texas at Austin.
- Van Nest, J.
1985 Patination of Knife River Flint Artifacts. *Plains Anthropologist* 30(110):325-339.
- Vayda, A. P., and R. A. Rappaport
1968 Ecology, Cultural and Noncultural. In *Introduction to Cultural Anthropology*, edited by James Clifton, pp. 447-496. Houghton Mifflin, New York.
- Vesceleus, G. S.
1960 Archaeological sampling: A problem of statistical inference. In *Essays in the Science of Culture, Essays in Honor of Leslie A. White*, edited by G. A. Dole and R. L. Carniero, pp. 457-470. Thomas Crowell, New York.
- Vogel, J. C., and N. J. Van der Merwe
1977 Isotopic Evidence for Early Maize Cultivation in New York State. *American Antiquity* 42:238-242.
- Walther, R., and D. Zilles
1994 ESR studies on flint with a difference-spectrum method. *Quaternary Geochronology* (Quaternary Science Reviews) 13:635-639.
- Wandsnider, L.
1988 Experimental investigation of the effect of dune processes on archeological remains. *American Archeology* 7(1):18-29.
- Watson, P. J.
1974 Theoretical and Methodological Difficulties Encountered in Dealing with Paleofecal Material. In *Archaeology of the Mammoth Cave Area*, edited by P. J. Watson, pp. 239-241. Academic Press, New York.
- Waters, M. R.
1992 *Principles of Geoarchaeology: A North American Perspective*. Tucson: University of Arizona Press.
-

Way, K. L.

1979 Early Pueblo Occupation in the Southern Tularosa Basin, New Mexico. In *Jornada Mogollon Archaeology: Proceedings of the First Jornada Conference*, edited by P. H. Beckett and R. N. Wiseman, pp. 41-52. New Mexico State University, Las Cruces.

Weather Bureau

1964 *Decennial Census of the United States Climate; Climatic Summary of the United States*. Washington, D.C., U.S. Department of Commerce.

Weatherwax, P.

1954 *Indian Corn in Old America*. MacMillian, New York.

Weber, R. H., and F. Kottowski

1959 Gypsum Resources of New Mexico. *New Mexico State Bureau of Mines and Mineral Resources Bulletin* 68, Socorro.

Weber, R. H., and G. A. Agogino

1968 Mockingbird Gap Paleo-Indian Site: Excavations in 1967. Paper presented at the 33rd Annual Meeting of the Society for American Archaeology, Santa Fe, New Mexico.

Weigand, P. C., G. Harbottle, and E. V. Sayre

1977 Turquoise Sources and Source Analysis: Mesoamerica and The Southwestern USA. In *Exchange Systems in Prehistory*, edited by T. K. Earle and J. E. Ericson. Academic Press, New York.

Weigand, P. C., and G. Harbottle

1992 The Role of Turquoise in the Ancient Mesoamerican Trade Structure. In *The American Southwest and Mesoamerica: Systems of Prehistoric Exchange*, edited by J. E. Ericson and T. G. Baugh. Plenum Press, New York.

Wells, P. V.

1966 Late Pleistocene vegetation and degree of pluvial climatic change in the Chihuahuan Desert. *Science* 153:970-975.

Wells, S. G., and J. D. Dohrenwend

1985 Relict sheetflood bedforms on late Quaternary alluvial-fan surfaces in the southwestern U.S. *Geology* 13:512-516.

Wells, S. G., L. D. McFadden, and J. C. Dohrenwend

1987 Influence of climatic changes on geomorphic and pedogenic processes on a desert piedmont, eastern Mojave Desert, California. *Quaternary Research* 27:130-146.

Wells, S. G., L. D. McFadden, and J. B. Ritter

1990 Reply to R. LeB. Hooke's Discussion of Use of Multiparameter Relative-Age Methods for Age Estimation and Correlation of Alluvial Fan Surfaces on a Desert Piedmont, Eastern Mojave Desert, California. *Quaternary Research* 34:263-265.

Wells, S. G., L. D. McFadden, J. Poths, and C. T. Olinger

1995 Cosmogenic ³He surface-exposure dating of stone pavements: Implications for landscape evolution in deserts. *Geology* 23(7):613-616.

West, K. L.

1982 *A Study of El Paso Brown Rim Form*. Unpublished M.A. thesis, University of Texas at El Paso, El Paso.

Wetterstrom, W. E.

1978 Plant Remains from Mesilla and El Paso Phase Sites of the Hueco Bolson: A Preliminary Report on Plant Foods Appendix F, Settlement Patterns of the Western Hueco Bolson. Historic and Natural Resources Report, U.S. Army, Fort Bliss, Environmental Office, DFAE, El Paso. *Publications in Anthropology No. 6*, El Paso Centennial Museum, The University of Texas at El Paso.

Whalen, M. E.

1977 Settlement Patterns of the Eastern Hueco Bolson. *Anthropological Paper Number 4*, Centennial Museum, University of Texas at El Paso.

1978 Settlement Patterns of the Western Hueco Bolson. *Anthropological Paper Number 6*, Centennial Museum, University of Texas at El Paso.

1979 Social Organization and Interaction During the Pithouse Period in the Jornada Area. In *Jornada Mogollon Archaeology: Proceedings of the First Jornada Conference*, edited by P. H. Beckett and R. N. Wiseman, pp. 345-358. New Mexico State University, Las Cruces.

1980 Special Studies in the Archaeology of the Hueco Bolson. Cultural and Natural Resources Report, U.S. Army, Fort Bliss Environmental Office, DFAE, Number 2. *Anthropological Paper No. 9*, El Paso Centennial Museum, University of Texas at El Paso, El Paso.

1981a Cultural-Ecological Aspects of The Pithouse-To-Pueblo Transition in a Portion of the Southwest. *American Antiquity* 46(1):75-92.

1981b Origin and Evolution of Ceramics in Western Texas. *Bulletin of the Texas Archaeological Society* 52:215-229.

1985 Dating the Past in Western Trans Pecos. *Bulletin of the Texas Archeological Society* 54:239-252.

1986 Small-Site Analysis in the Hueco Bolson of Western Texas. *Journal of Field Archaeology* 13(1):69-81.

1987 The Bruton Bead Site and Pueblo Period Exchange in Southern New Mexico. *American Archeology* 6(3):173-178

1993 El Paso Plain Brown Rims as Chronological Markers? New Data on an Old Question. *Kiva* 58:475-4486.

1994 Turquoise Ridge and Late Prehistoric Residential Mobility in the Desert Mogollon Region. *University of Utah Anthropological Papers Number 118*, University of Utah Press, Salt Lake City.

White, S. E., and S. Valastro, Jr.

1984 Pleistocene glaciation of Volcano Ajusco, Central Mexico, and comparison with the standard Mexican glacial sequence. *Quaternary Research* 21:21-35.

White, T. E.

1953 A method of calculating the dietary importance of various food animals utilized by aboriginal peoples. *American Antiquity* 18:396-398.

Whittow, J.

1984 *The Penguin Dictionary of Physical Geography*. Penguin Books, New York.

Wilding, L. P.

1967 Radiocarbon dating of biogenetic opal. *Science* 156:66-67.

Willey, G. R., and J. A. Sabloff

1980 *A History of American Archaeology*. Second Edition, W. H. Freeman, San Francisco, California.

Williams, G. E., and H. A. Polach

1969 The evaluation of C-14 ages for soil carbonate from the arid zone. *Earth and Planetary Science Letters* 7:240-242.

1971 Radiocarbon dating of arid zone calcareous paleosols. *Geological Society of America Bulletin* 82:3,069-3,086.

Williams, S. H., and J. R. Zimbleman

1994 Desert pavement evolution: An example of the role of sheetflood. *Journal of Geology* 102:243-248.

Wilson, I. G.

1972 Aeolian bedforms--their development and origins. *Sedimentology* 19:173-210.

Wimberly, M., and A. Rodgers

1977 Archaeological Survey, Three Rivers Drainage, New Mexico: Cultural Succession, A Case Study. *The Artifact* 15:1-478.

Winner, L.

1977 *Autonomous Technology: Tecnics-out-of-Control as a Theme in Political Thought*. MIT Press, Cambridge, Massachusetts.

Winsborough, B.

1994 Appendix C: Diatom analysis from Sulphur Springs Reservoir. In *Sulphur Springs Draw: Geoarchaeological and Archaeological Investigations at Sulphur Draw Reservoir, Martin County, Texas*, by J. M. Quigg, C. D. Frederick, and C. Lintz, pp. C1-C2. Mariah Associates Technical Report No. 776, Austin.

Wintle, A. G.

1993 Luminescence dating of eolian sands: An overview. In *The Dynamics and Environmental Context of Aeolian Sedimentary Systems*, edited by K. Pye, pp. 49-58. Geological Society of America Special Publication No. 72.

Wintle, A. G., and D. J. Huntley

1982 Thermoluminescence dating of sediments. *Quaternary Science Reviews* 1:31-53.

Wintle, A. G., N. Lancaster, and S. R. Edwards

1994 Infrared stimulated luminescence (IRSL) dating of late Holocene dune sands in the Mojave Desert, California. *The Holocene* 4:74-78.

Wiseman, R. N.

1981 Playas Incised, Sierra Blanca Variety: A New Pottery Type in the Jornada Mogollon. In *Transactions of the 16th Regional Archaeological Symposium for Southeastern New Mexico and Western Texas*, pp. 21-27. Midland Archaeological Society, Midland, Texas.

-
- 1982 The Intervening Years - New Information on Chupadero Black-on-White and Corona Corrugated. *Pottery Southwest* 9(4):5-7. Albuquerque Archaeological Society, Santa Fe, New Mexico.
- 1991 *The Bent Project*. COAS Monographs. COAS Publishing and Research, Las Cruces, New Mexico.
- Woodruff, C. M., Jr., T. C. Gustavson, and R. J. Finley
1979 Playas and draws on the Llano Estacado--Tentative findings based on geomorphic mapping of a test area in Texas. *Texas Journal of Science* 31(3):213-223.
- Wooldridge, H. G.
1979 *The Bald Eagle Cache: Implications of An Early Exchange System in the Jornada Region of South-Central New Mexico*. Unpublished M.A. thesis, Department of Anthropology, The University of Texas at Austin.
- Wright, K. L.
1994 Ground-Stone Tools and Hunter-Gatherer Subsistence in Southwest Asia: Implications for the Transition to Farming. *American Antiquity* 59:238-263.
- Wright, R. A.
1960 *Increase of Mesquite On A Southern New Mexican Desert Grassland Range*. Unpublished M.S. thesis, New Mexico State University, University Park.
- Yaalon, D. H., and E. Ganor
1973 The influence of dust on soil during the Quaternary. *Soil Science* 116:146-155.
- Yellen, J. E.
1976 Settlement Patterns of the !Kung: An Archaeological Perspective. In *Kalahari Hunter-Gatherers Studies of the !Kung San and Their Neighbors*, pp. 47-72, edited by Richard B. Lee and Irven DeVore. Harvard University Press. Cambridge, Massachusetts.
- 1977 *Archaeological Approaches to the Present: Models for Reconstructing the Past*. Academic Press, New York.
- Yellen, J. E., and R. B. Lee
1976 The Dobe-/Du/da Environment: Background to a Hunting and Gathering Way of Life. In *Kalahari Hunter-Gatherers: Studies of the !Kung San and Their Neighbors*, edited by R. B. Lee and I. DeVore, pp. 27-46. Harvard University Press, Cambridge, Massachusetts.
- 1978 Long-Term Hunter-Gatherer Adaptation to Desert Environments: A Biogeographical Perspective. *World Archaeology* 8:262-274.
- York, J. C., and W. A. Dick-Peddie
1969 Vegetation changes in southern New Mexico during the past hundred years. In *Arid Lands in Perspective*, edited by W. G. McGinnies and B. J. Goldman, pp. 155-166. University of Arizona Press, Tucson.
- Young, L. C.
1994 Lithics and Adaptive Diversity: An Examination of Limited-Activity Sites in Northeast Arizona. *Journal of Anthropological Research* 50:141-154.
-

APPENDIX A

Geoarcheological Field Form

FORT BLISS SITE EVALUATION

Quantitative Geoarcheological/Paleoenvironmental Assessment, page 1

SITE _____ Subsection(s) _____ Maneuver Area _____
Recorder _____ Date _____

CONTEXT

Surface Type (circle only one)

bedrock upland

- 4 level
- 2 sloping

aeolian sheet sands

- 6 thin (< 1 m) discontinuous
- 9 thin (<1 m) continuous
- 10 thick (> 1m) continuous

older alluvial fan

- 8 fine sediment mantle
- 4 desert pavement
- 1 stripped calcrete

colluvial/scree slope

- 4 gentle
- 4 moderate
- 2 steep

coppice dunes

- 6 erosional interdunes
- 8 sand sheets in interdunes

younger alluvial fan

- 6 dom. coarse grained sediment
- 8 mixed-load sediment
- 9 dom. fine-grained sediment

deflated bolson surface

- 4 artifact clusters present
- 1 no artifact clusters present

large dunes

- 8 eroded interdunes
- 10 sheet sands in interdunes

fan channel fill

- 4 domin. coarse grained sediment
- 8 mixed-load sediment
- 9 domin. fine-grained sediment

playa / playa periphery

- 7 small (<50 m diameter) playa
- 9 large (>50 m diameter) playa

rockshelter / cave

- 6 minimal deposits
- 8 obvious deposits

Age of Geomorphic Surface (circle one)

- 1 ancient (>15,000 yrs; strong Bt, K) e.g., La Mesa, Jornada I, Jornada II
- 8 moderate (15,000-2,000 yrs; weak-moderate Bt, Bk, rubification) e.g., Isaack's Ranch, Organ II
- 8 young (2,000-100 yrs; weak Bk, A) e.g., Organ II-III
- 4 recent (no soil development, primary stratification) e.g., modern coppice dunes

Position and Context of Cultural Remains (circle one)

- | | | | |
|----|---------------------|---|--------------------------------|
| 6 | surface (clustered) | 9 | buried and surface (clustered) |
| 4 | surface (dispersed) | 8 | buried and surface (dispersed) |
| 10 | buried | 7 | unknown |

CONTEXT TOTAL: _____ (possible range = 6 to 28)

INTEGRITY

Deposits of Late Pleistocene/Holocene Age (circle one in each category)

Presence

- 5 present
- 1 absent
- 3 unknown

Continuity

- 1 discrete
- 3 continuous
- 2 unknown

Thickness

- 3 > 1 m
- 2 25 cm- 1 m
- 1 < 25 cm

Apparent Spatial Integrity of Archeological Data (circle one)

- | | | | |
|---|----------------------------|---|-----------------|
| 5 | high (strong clustering) | 1 | low (dispersed) |
| 3 | moderate (some clustering) | 3 | unknown |

Apparent Stratigraphic Integrity of Archeological Data (circle one)

- | | | | | | |
|---|--------------------------------------|---|---------------------------------|---|---------|
| 5 | high (discrete archeological strata) | 2 | low (dispersed) | 3 | unknown |
| 4 | moderate (diffuse artifact zones) | 1 | none (surfacial artifacts only) | | |

Quantitative Geoarchaeological/Paleoenvironmental Assessment, page 2

SITE Subsection(s):

2 **high** **3** **moderate** **5** **low**

2 high 3 moderate 5 low

Integrity Subtotal: (possible range = 9 to 31)

Palimpsest Multiplier

If assemblage *clearly* contains *only* multiple, inseparable temporal components, (e.g., as indicated by abundant diagnostics of different ages and complete absence of potential stratigraphic integrity) multiply preliminary score by 0.5:

If assemblage is *clearly* single component (e.g., contains a large sample of diagnostic artifacts representing only a single time period) or contains discrete, stratigraphically separable temporal components in unambiguous depositional context, multiply preliminary score by 2:

otherwise, multiply by 1:

Total Geoarchaeological Score (possible range = 7.5 to 118)

charcoal (choose only one)

- 20 large quantities (e.g. 3 g+) of potentially identifiable charcoal in feature context
10 large quantities (e.g. 3 g+) of potentially identifiable charcoal in non-feature context
10 concentrated charcoal flecks/ stains
5 dispersed charcoal flecks/ stains

animal bone (choose only one)

- 10 non-recent animal bone exhibiting evidence of cultural modification (e.g., burning, cutmarks)
5 non-recent animal bone, no evidence of human modification

Other (circle all that apply)

- | | |
|----|--|
| 20 | human bone |
| 10 | macrobotanical remains (including old wood in archeological association) |
| 2 | land snails |
| 5 | other shell |
| 3 | clayey or laminated silty sediments with potential for pollen / diatom / ostracod preservation (e.g., playa sediments, spring sediments) |
| 5 | buried, untruncated or lightly truncated paleosols |
| 3 | buried truncated paleosols |
| 5 | preserved eolian stratigraphy |
| 5 | preserved alluvial stratigraphy |
| 5 | preserved colluvial stratigraphy |
| 15 | tufa / travertine / speleothems |
| 10 | cave / rockshelter fill |
| 2 | soil carbonates |

Total Paleoenvironmental Score (possible range = 0 to 110)

FORT BLISS SITE EVALUATION
Descriptive Geomorphic Assessment

SITE NO.: _____ **Subsection(s):** _____ **Maneuver Area:** _____
Recorder: _____ **Date:** _____

OBSERVATIONS

Natural Exposures (for each: type of exposure, depth, location, depositional agent(s), sediment type, cultural manifestations, features)

Mechanical Exposures (for each: location, depth, cultural features)

Geomorphic Surfaces (depositional agent(s), relief, relative height)

Sediment Columns (for each: depositional agent(s), textural trends, facies, unconformities)

Soil Profiles (for each: horizon sequence, parent material, age estimate, integrity assessment)

Disturbance (form, extent, location)

Surface or Subsurface Visibility (vegetation type, density, location of visible surfaces, % visible)

Potential Sources of Paleoenvironmental Data (e.g., charcoal, snails, pedogenic carbonates, palustrine/playa sediments)

Fort Bliss Site Evaluation

Descriptive Geomorphic Assessment, page 2

SITE _____, Subsection(s) _____

INTERPRETATIONS

Depositional Processes and Events (number, process, age)

Erosional Events (number, process, age)

Integrity (qualitative assessment, justification)

Cultural Manifestations (number, type, extent, density, features, age)

CONCLUSIONS

Qualitative Evaluation of Site Context (relative area of potential deposits, thickness, number of occupations)

Stratified Archaeological Deposits (present/absent, type, relative density, level of integrity)

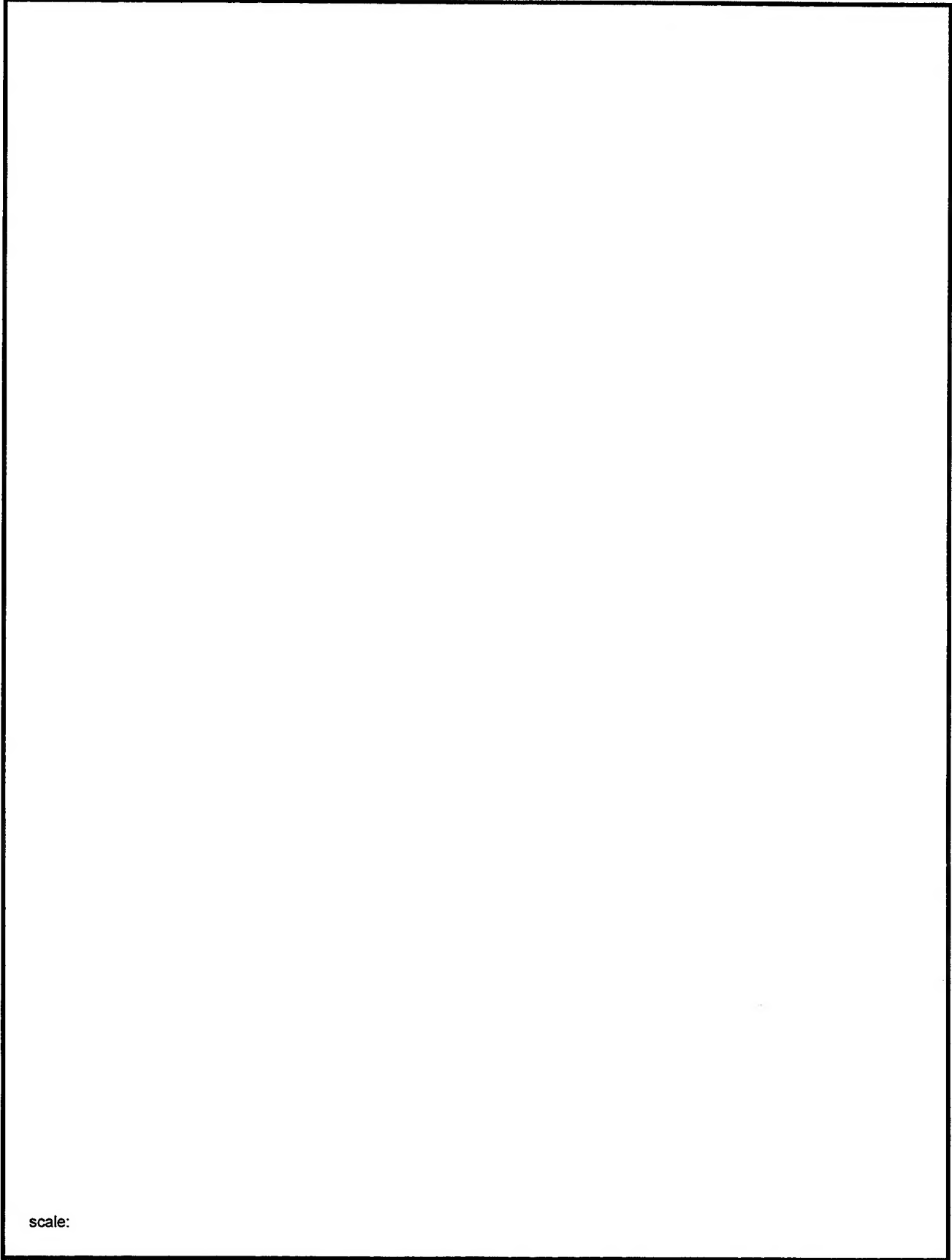
Paleoenvironmental Potential (potential avenues of paleoenvironmental investigation, justification)

Fort Bliss Site Evaluation

Descriptive Geomorphic Assessment, page 3

SITE _____ Subsection(s) _____

Site Sketch Map

A large, empty rectangular box with a black border, intended for a site sketch map. It occupies the majority of the page below the header.

scale:

Fort Bliss Site Evaluations

Descriptive Geomorphic Assessment, Page 4

SITE _____, Subsection(s) _____

COMMENTS, SKETCHES:

Field Exposure Description Form

Profile Designation _____ Date _____
 Described by _____ Sampled By _____ Sample Types _____
 Location _____ Quadrange _____ Geologic Unit _____
 Nature, texture of deposit _____ Geom. Surface _____
 Remarks _____

| Zone | Depth | Horiz |
|--|--|---|
| Texture: F/M/C Grvly/Sndy/Slt/Cly/Lmy Gravel/Sand/Silt/Clay/Loam | Struct: Mas/Blky/Pty/Colmn/Prism/Gran/Crum VF/F/M/C/V/C Wk/Md/St | Consist: VFr/Fr/Fm/VFm Ls/Si/SHd/Hd/VHd NSu/SSu/Su/VSt NP/SP/P/VP |
| Reaction N/W/M/S/V Mottles N/F/C/A F/M/C Faint/Dist/Prom | Bdry: Abr/Clr/Grad/Diff Smooth/Wavy/Irreg/Broken Color: _____ | CaCO3 Morph: F/C/A None/filam/film/rhiz/nod(l/m/c) Roots: N/F/C/A |
| Comment: _____ | | |
| Zone | Depth | Horiz |
| Texture: F/M/C Grvly/Sndy/Slt/Cly/Lmy Gravel/Sand/Silt/Clay/Loam | Struct: Mas/Blky/Pty/Colmn/Prism/Gran/Crum VF/F/M/C/V/C Wk/Md/St | Consist: VFr/Fr/Fm/VFm Ls/Si/SHd/Hd/VHd NSu/SSu/Su/VSt NP/SP/P/VP |
| Reaction N/W/M/S/V Mottles N/F/C/A F/M/C Faint/Dist/Prom | Bdry: Abr/Clr/Grad/Diff Smooth/Wavy/Irreg/Broken Color: _____ | CaCO3 Morph: F/C/A None/filam/film/rhiz/nod(l/m/c) Roots: N/F/C/A |
| Comment: _____ | | |
| Zone | Depth | Horiz |
| Texture: F/M/C Grvly/Sndy/Slt/Cly/Lmy Gravel/Sand/Silt/Clay/Loam | Struct: Mas/Blky/Pty/Colmn/Prism/Gran/Crum VF/F/M/C/V/C Wk/Md/St | Consist: VFr/Fr/Fm/VFm Ls/Si/SHd/Hd/VHd NSu/SSu/Su/VSt NP/SP/P/VP |
| Reaction N/W/M/S/V Mottles N/F/C/A F/M/C Faint/Dist/Prom | Bdry: Abr/Clr/Grad/Diff Smooth/Wavy/Irreg/Broken Color: _____ | CaCO3 Morph: F/C/A None/filam/film/rhiz/nod(l/m/c) Roots: N/F/C/A |
| Comment: _____ | | |
| Zone | Depth | Horiz |
| Texture: F/M/C Grvly/Sndy/Slt/Cly/Lmy Gravel/Sand/Silt/Clay/Loam | Struct: Mas/Blky/Pty/Colmn/Prism/Gran/Crum VF/F/M/C/V/C Wk/Md/St | Consist: VFr/Fr/Fm/VFm Ls/Si/SHd/Hd/VHd NSu/SSu/Su/VSt NP/SP/P/VP |
| Reaction N/W/M/S/V Mottles N/F/C/A F/M/C Faint/Dist/Prom | Bdry: Abr/Clr/Grad/Diff Smooth/Wavy/Irreg/Broken Color: _____ | CaCO3 Morph: F/C/A None/filam/film/rhiz/nod(l/m/c) Roots: N/F/C/A |
| Comment: _____ | | |
| Zone | Depth | Horiz |
| Texture: F/M/C Grvly/Sndy/Slt/Cly/Lmy Gravel/Sand/Silt/Clay/Loam | Struct: Mas/Blky/Pty/Colmn/Prism/Gran/Crum VF/F/M/C/V/C Wk/Md/St | Consist: VFr/Fr/Fm/VFm Ls/Si/SHd/Hd/VHd NSu/SSu/Su/VSt NP/SP/P/VP |
| Reaction N/W/M/S/V Mottles N/F/C/A F/M/C Faint/Dist/Prom | Bdry: Abr/Clr/Grad/Diff Smooth/Wavy/Irreg/Broken Color: _____ | CaCO3 Morph: F/C/A None/filam/film/rhiz/nod(l/m/c) Roots: N/F/C/A |
| Comment: _____ | | |

Abbreviation Key Texture: Fine/Medium/Coarse; Gravelly/Sandy/Silty/Clayey/Loamy; Structure: Massive/Blocky/Platy/Columnar/Prismatic/Granular/Crumb; Very Fine/Fine/Medium/Coarse/Very Coarse; Weak/Moderate/Strong; Consistence: Very friable/friable/Firm/very firm; Loose/soft/slightly hard/hard/very hard; Non-sticky—very sticky; nonplastic—very plastic; Reaction (HCl): None/weak/moderate/strong/violent; Mottles: None/few/common/abundant; fine/medium/coarse; faint/distinct/prominent; Boundary: Abrupt/Clear/Gradual/Diffuse; CaCO3 Morphology: few/common/abundant None/filaments/films/rhizoliths/nodules (fine/medium/coarse)

| | | | |
|---|-------------|-------------|--|
| Zone _____ | Depth _____ | Horiz _____ | Texture: F/M/C Grvly/Sndy/Slt/Cly/Lmy Gravel/Sand/Silt/Clay/Loam |
| Struct: Mas/Blky/Pty/Colmn/Prism/Gran/Crum VF/F/M/C/V C Wk/Md/Str | | | Bdry: Abr/Clr/Grad/Diff Smooth/Wavy/Irreg/Broken |
| Consist: VFr/Fr/Fm/VFm Ls/St/SHd/Hd/VHd NSu/SSu/St/VSt NP/SP/P/VP | | | Roots: None/Few/Common/Abundant Color: _____ |
| Reaction N/W/M/S/V Mottles N/F/C/A F/M/C Faint/Dist/Prom | | | CaCO3 Morph: F/C/A None/filam/film/thiz/nod(f/m/c) |
| Comment: _____ | | | |

| | | | |
|---|-------------|-------------|--|
| Zone _____ | Depth _____ | Horiz _____ | Texture: F/M/C Grvly/Sndy/Slt/Cly/Lmy Gravel/Sand/Silt/Clay/Loam |
| Struct: Mas/Blky/Pty/Colmn/Prism/Gran/Crum VF/F/M/C/V C Wk/Md/Str | | | Bdry: Abr/Clr/Grad/Diff Smooth/Wavy/Irreg/Broken |
| Consist: VFr/Fr/Fm/VFm Ls/St/SHd/Hd/VHd NSu/SSu/St/VSt NP/SP/P/VP | | | Roots: None/Few/Common/Abundant Color: _____ |
| Reaction N/W/M/S/V Mottles N/F/C/A F/M/C Faint/Dist/Prom | | | CaCO3 Morph: F/C/A None/filam/film/thiz/nod(f/m/c) |
| Comment: _____ | | | |

| | | | |
|---|-------------|-------------|--|
| Zone _____ | Depth _____ | Horiz _____ | Texture: F/M/C Grvly/Sndy/Slt/Cly/Lmy Gravel/Sand/Silt/Clay/Loam |
| Struct: Mas/Blky/Pty/Colmn/Prism/Gran/Crum VF/F/M/C/V C Wk/Md/Str | | | Bdry: Abr/Clr/Grad/Diff Smooth/Wavy/Irreg/Broken |
| Consist: VFr/Fr/Fm/VFm Ls/St/SHd/Hd/VHd NSu/SSu/St/VSt NP/SP/P/VP | | | Roots: None/Few/Common/Abundant Color: _____ |
| Reaction N/W/M/S/V Mottles N/F/C/A F/M/C Faint/Dist/Prom | | | CaCO3 Morph: F/C/A None/filam/film/thiz/nod(f/m/c) |
| Comment: _____ | | | |

| | | | |
|---|-------------|-------------|--|
| Zone _____ | Depth _____ | Horiz _____ | Texture: F/M/C Grvly/Sndy/Slt/Cly/Lmy Gravel/Sand/Silt/Clay/Loam |
| Struct: Mas/Blky/Pty/Colmn/Prism/Gran/Crum VF/F/M/C/V C Wk/Md/Str | | | Bdry: Abr/Clr/Grad/Diff Smooth/Wavy/Irreg/Broken |
| Consist: VFr/Fr/Fm/VFm Ls/St/SHd/Hd/VHd NSu/SSu/St/VSt NP/SP/P/VP | | | Roots: None/Few/Common/Abundant Color: _____ |
| Reaction N/W/M/S/V Mottles N/F/C/A F/M/C Faint/Dist/Prom | | | CaCO3 Morph: F/C/A None/filam/film/thiz/nod(f/m/c) |
| Comment: _____ | | | |

| | | | |
|---|-------------|-------------|--|
| Zone _____ | Depth _____ | Horiz _____ | Texture: F/M/C Grvly/Sndy/Slt/Cly/Lmy Gravel/Sand/Silt/Clay/Loam |
| Struct: Mas/Blky/Pty/Colmn/Prism/Gran/Crum VF/F/M/C/V C Wk/Md/Str | | | Bdry: Abr/Clr/Grad/Diff Smooth/Wavy/Irreg/Broken |
| Consist: VFr/Fr/Fm/VFm Ls/St/SHd/Hd/VHd NSu/SSu/St/VSt NP/SP/P/VP | | | Roots: None/Few/Common/Abundant Color: _____ |
| Reaction N/W/M/S/V Mottles N/F/C/A F/M/C Faint/Dist/Prom | | | CaCO3 Morph: F/C/A None/filam/film/thiz/nod(f/m/c) |
| Comment: _____ | | | |

| | | | |
|---|-------------|-------------|--|
| Zone _____ | Depth _____ | Horiz _____ | Texture: F/M/C Grvly/Sndy/Slt/Cly/Lmy Gravel/Sand/Silt/Clay/Loam |
| Struct: Mas/Blky/Pty/Colmn/Prism/Gran/Crum VF/F/M/C/V C Wk/Md/Str | | | Bdry: Abr/Clr/Grad/Diff Smooth/Wavy/Irreg/Broken |
| Consist: VFr/Fr/Fm/VFm Ls/St/SHd/Hd/VHd NSu/SSu/St/VSt NP/SP/P/VP | | | Roots: None/Few/Common/Abundant Color: _____ |
| Reaction N/W/M/S/V Mottles N/F/C/A F/M/C Faint/Dist/Prom | | | CaCO3 Morph: F/C/A None/filam/film/thiz/nod(f/m/c) |
| Comment: _____ | | | |

| | | | |
|---|-------------|-------------|--|
| Zone _____ | Depth _____ | Horiz _____ | Texture: F/M/C Grvly/Sndy/Slt/Cly/Lmy Gravel/Sand/Silt/Clay/Loam |
| Struct: Mas/Blky/Pty/Colmn/Prism/Gran/Crum VF/F/M/C/V C Wk/Md/Str | | | Bdry: Abr/Clr/Grad/Diff Smooth/Wavy/Irreg/Broken |
| Consist: VFr/Fr/Fm/VFm Ls/St/SHd/Hd/VHd NSu/SSu/St/VSt NP/SP/P/VP | | | Roots: None/Few/Common/Abundant Color: _____ |
| Reaction N/W/M/S/V Mottles N/F/C/A F/M/C Faint/Dist/Prom | | | CaCO3 Morph: F/C/A None/filam/film/thiz/nod(f/m/c) |
| Comment: _____ | | | |

| | | | |
|---|-------------|-------------|--|
| Zone _____ | Depth _____ | Horiz _____ | Texture: F/M/C Grvly/Sndy/Slt/Cly/Lmy Gravel/Sand/Silt/Clay/Loam |
| Struct: Mas/Blky/Pty/Colmn/Prism/Gran/Crum VF/F/M/C/V C Wk/Md/Str | | | Bdry: Abr/Clr/Grad/Diff Smooth/Wavy/Irreg/Broken |
| Consist: VFr/Fr/Fm/VFm Ls/St/SHd/Hd/VHd NSu/SSu/St/VSt NP/SP/P/VP | | | Roots: None/Few/Common/Abundant Color: _____ |
| Reaction N/W/M/S/V Mottles N/F/C/A F/M/C Faint/Dist/Prom | | | CaCO3 Morph: F/C/A None/filam/film/thiz/nod(f/m/c) |
| Comment: _____ | | | |

General Comments _____